Rock Mechanics and Tunneling
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Lecture 40
Slopes (Continued)

Hello, everyone, I welcome all of you to the 4th lecture of module 8. So, in module 8 we are discussing about the slopes and underground excavation. As I have stated, we have mainly dedicated our time on slope stability analysis. So, earlier we have discussed about different things like different types of slopes and different modes of failure like plane failure and then wedge failure toppling and also in our last class we have discussed about the circular failure.

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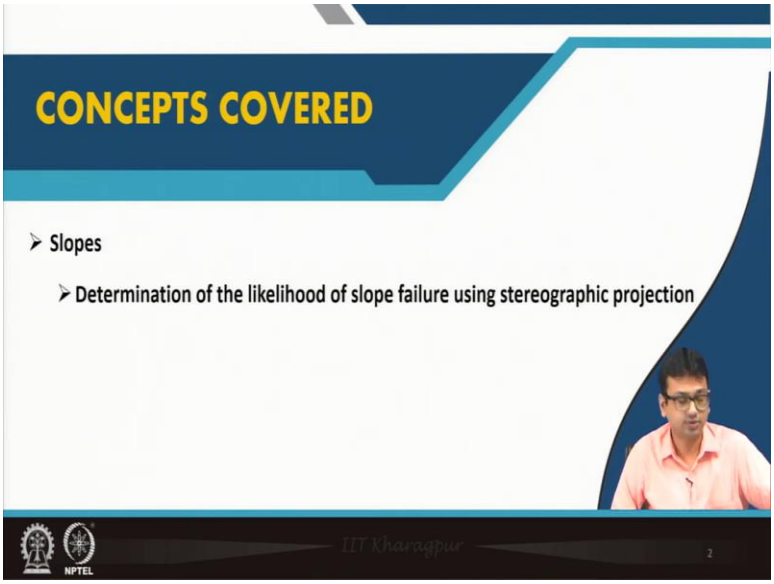

Today, we will discuss a little bit different things basically, that is the determination of the likelihood of slope failure using stereographic projection.

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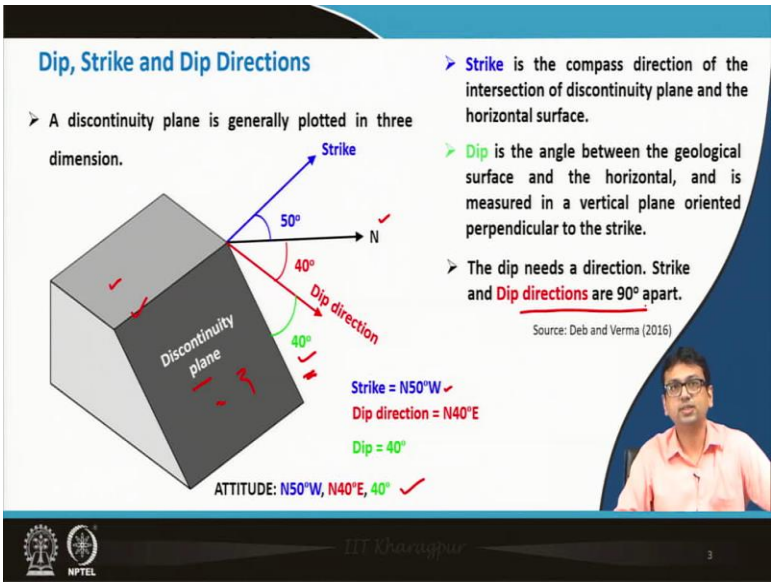

So, whether there is any chance of failure or not that we will try to understand through stereographic projection. So, I think before directly starting the problem, I will explain it through one problem. But before that, let us revisit our some of the terminologies what we have learned earlier in our first module. So, what are they like dip, strike, dip directions all these things. So, as we know a discontinuity plane is generally plotted in three dimensions.

Now, if this is suppose the discontinuity plane and this is the horizontal. So, then you see here the discontinuity plane is intersecting with the horizontal plane. So, now, if it is my north direction, then this is nothing but my strike we know then suppose this angle is 50°, we can write strike is N50°W.

Now, the perpendicular to the strike is 50+40 = 90°, this line is nothing but the dip direction this horizontal mean the horizontal angle between strike and dip this they are perpendicular to each other. So, strike and dip directions they are perpendicular to each other 90° difference. So, we can write dip direction in N40°E.

Now, the vertical angle if we measure this vertical angle that will be given the name like dip that is the dip. So, together this strike, dip direction, dip is called as the attitude we know and in this way you can represent it N50°W, N40°E and 40°. So, this will indicate that sequence is like strike, dip direction and dip.

Now, let us quickly see the definitions like what we have learned earlier. Strike is the compass direction of the intersection of discontinuity plane and horizontal surface as I have mentioned or shown through this diagram. Then dip is the angle between the geological surface and the horizontal geological circle discontinuity this surface actually. So, this one and horizontal and is measured in a vertical plane so, this is a vertical plane in this vertical plane oriented perpendicular to the strike. So, this vertical plane is oriented perpendicular to the strike. So, you see strike and dip directions are 90 ° apart. The dip needs the direction, strike and dip directions are 90° apart, these are the things already we know.

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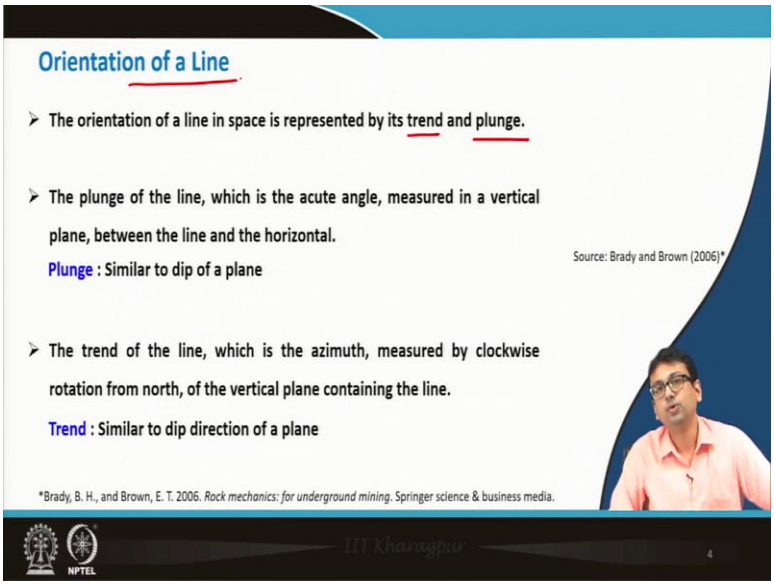

Now, whatever the orientation of a line we have discussed, the orientation of a plane is now orientation of a line, the orientation of a line in space is represented by its trend and plunge. The plunge of the line which is the acute angle measured in a vertical plane between the line and the horizontal and this plunge is similar to dip of the plane. Now, trend of the line which is the azimuth measured by clockwise rotation from the north of the vertical plane containing the line. So, now the trend is similar to the dip direction of a plane.

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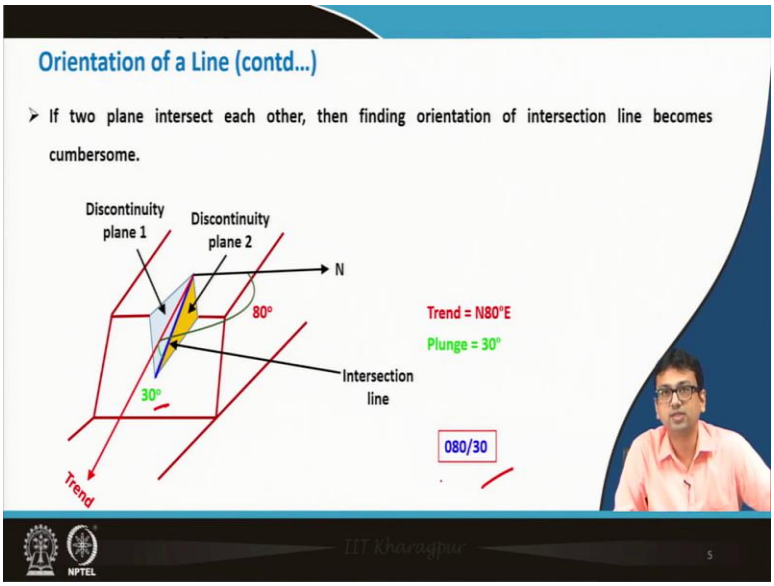

Now, if two plane intersect each other then finding the orientation of intersection line becomes quite cumbersome. So, basically what I mean to say you see now this with this type of diagram you are familiar like we can clearly understand probably the wedge failure has occurred here. So, this is support discontinuity plane 1 discontinuity plane 2 and this is nothing but the intersection line. Now, the orientation of this line we can represent through this trend and plunge you see now suppose it is the north then this will be the trend and trend will be supposed that is 80° suppose roughly you are taking.

So, now we can tell that the trend is N80°E, suppose then this vertical angle what you can see here this is suppose 30° that is nothing but my plunge. So, we could be able to define the orientation of this intersection line with the help of trend and plunge. So, this is sometimes represented in this form also which also indicate the first term indicates the trend second this plunge.

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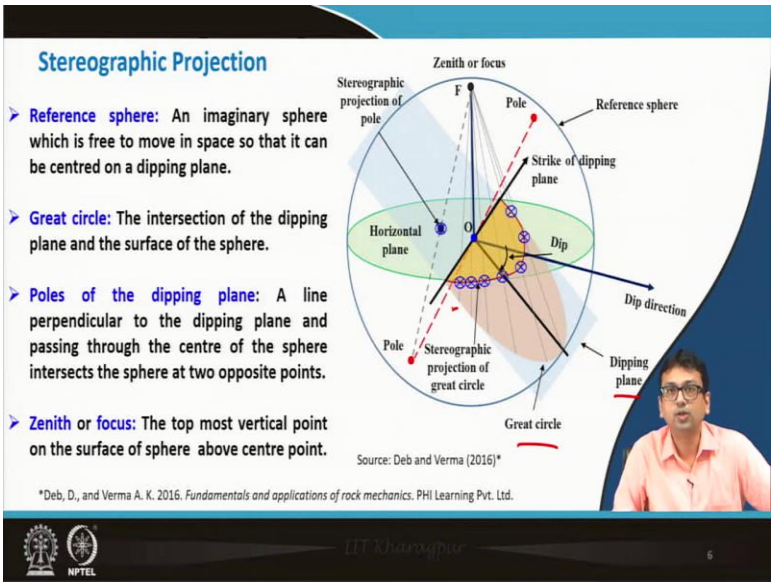

Now, let us quickly see the basics of stereographic projection what we have learned earlier also. So, suppose this is the dipping plane so, we have to consider reference sphere or imagine a reference sphere and the reference sphere is an imaginary sphere which is free to move in space so, that it can be centred on a dipping plane.

So, this is our reference sphere so, you have to imagine that. Now, this is the horizontal plane suppose, the intersection of the dipping plane and the surface of the sphere gives us the great circle.

Now, top part we can delete because same information we will get from upper part also have discussed about this earlier also. So, I hope you remember now this is nothing but the strike of dipping plane if you can consider then it is the dip direction and this is nothing but the dip. Now pole so, we have discovered poles also earlier and so, the pole of the dipping plane what is this a line perpendicular to the dipping plane and passing through the centre of the sphere intersects the sphere at two opposite points.

So, those two opposite points are nothing but the poles. Zenith or focus the top most vertical point on the surface of the sphere above centre point is called as the zenith or focus suppose if you this one of this pole from both these poles we will get the same information.

So, let us consider one pole. So if you connect F with one pole or it will intersect when the line will intersect the horizontal plane at sub-point, that is the nothing but the stereographic

projection of the pole. Now, similarly, about this great circle also we can get the projection of the great circle on this horizontal plane also.

So, if we can connect this F with this point suppose it will intersect the horizontal plane at this point likewise other points. So, now, if you connect those crosses, we get the stereographic projection of the great circle. Now, in this way you can construct this to stereo net.

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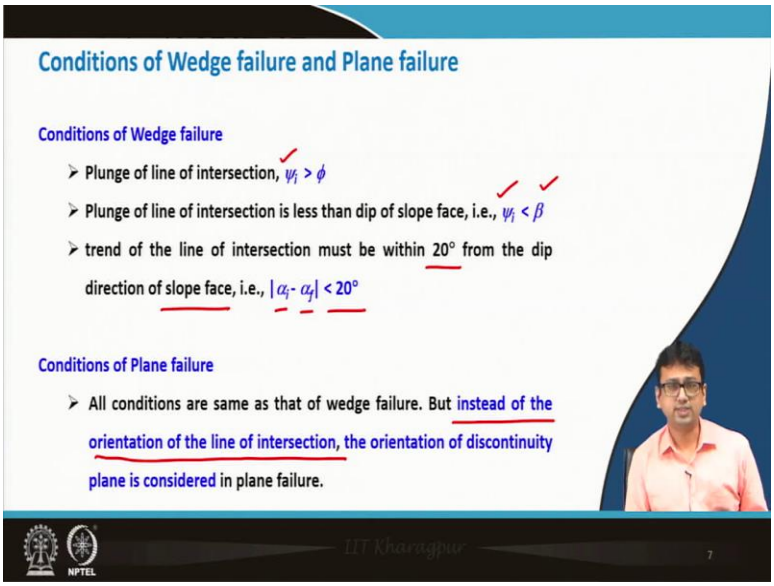

So, I think we have now good amount of information and we have revised it nicely now, let us see since we are interested in finding out the likelihood of slope failure. So, let us see the different conditions of wedge failure and plane failure. So, conditions of wedge failure I have discussed about this earlier also again it is written over here so plunge of the line of intersection this ψ_i should be greater than angle of internal friction ϕ, then plunge of the line of intersection is less than dip of the slope face.

So, ψ_i less than β and trend of the line of intersection must be within 20° from that dip direction of the slope face. So, slope face so, suppose if it is alpha i and slope face for slope is alpha f so, it should be mod this should be less than 20°. So, these are the three conditions if satisfied then we can say that there is a likelihood of wedge failure. Similarly, for plane failure all the conditions are same as that of the wedge failure but instead of the orientation of the line of intersection the orientation of discontinuity plane is considered in plane failure. So, very simple.

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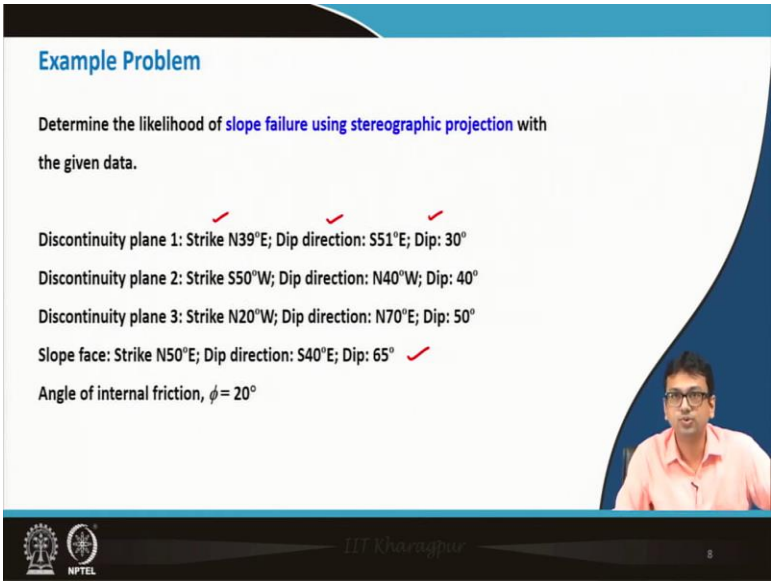

Now, let us take the problem. So, determine the likelihood of slope failure using stereographic projection with the given data. So, discontinuity plane 1 is having strike this dip direction these and dip is this. Likewise direct discontinuity plane 2 strike, dip direction dip is given likewise plane discontinuity plane 3 strike dip direction and dip is given also the slope face for that also strike dip direction and dip is provided and it is also stated that the angle of internal friction ϕ is equal to 20 °.

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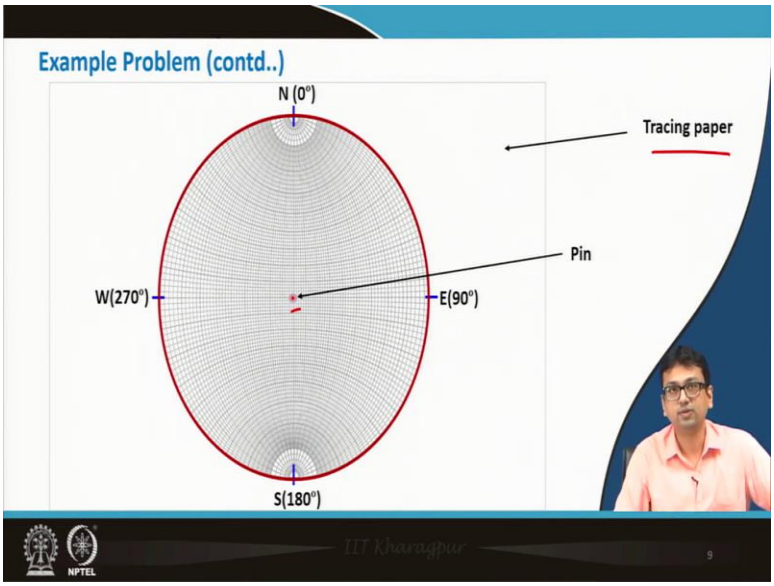
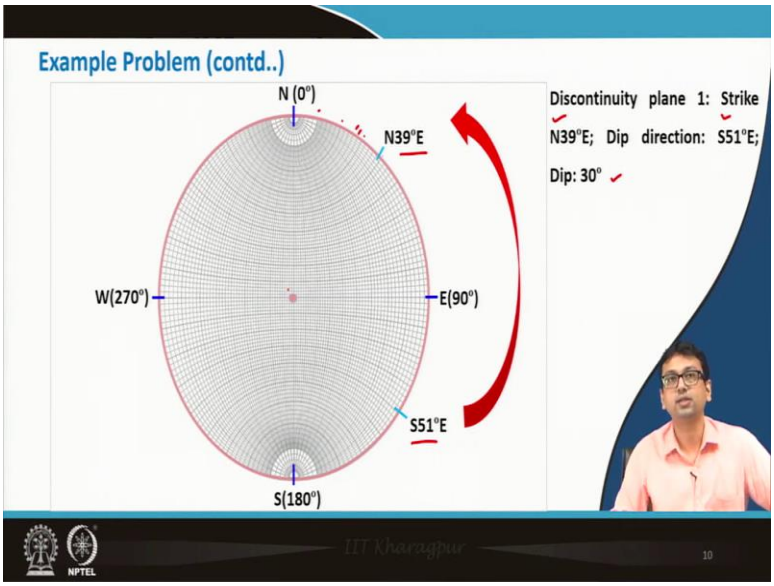
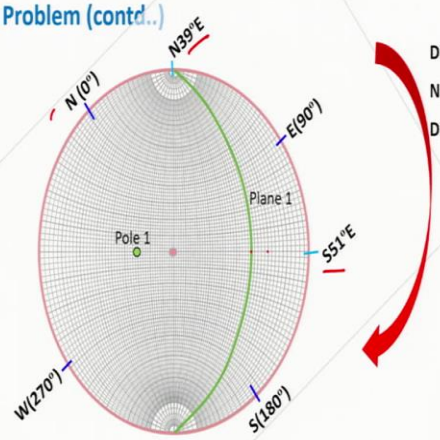


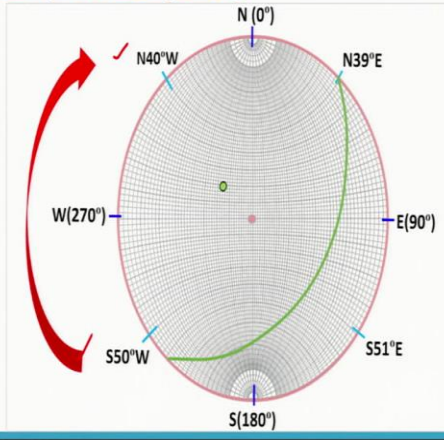


Example Problem (contd..)



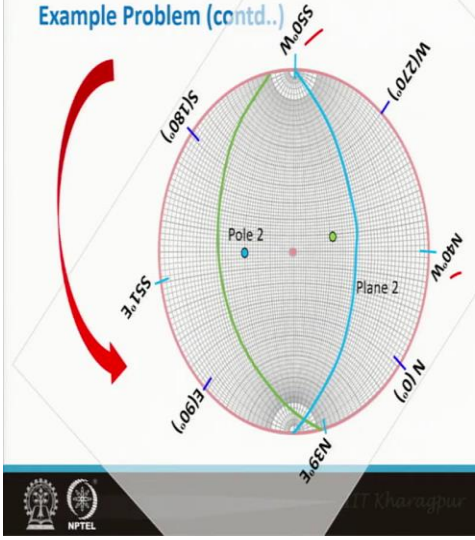
Discontinuity plane 1: Strike N39°E; Dip direction: S51°E; Dip: 30°

Example Problem (contd..)



Discontinuity plane 2: Strike S50°W; Dip direction: N40°W; Dip: 40°

Example Problem (contd..)



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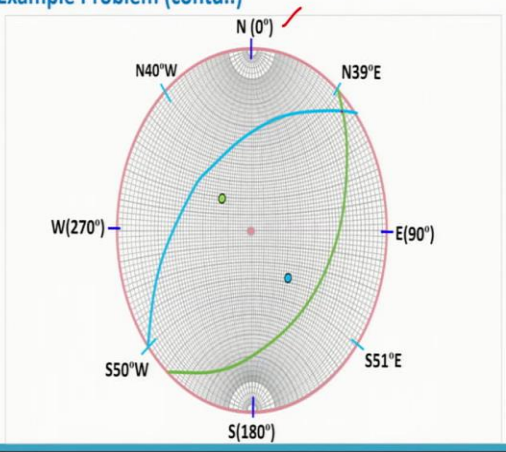
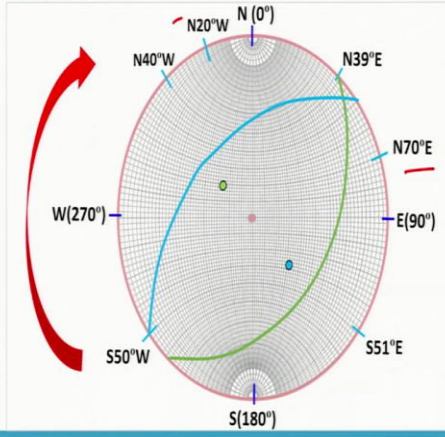
Example Problem (contd..)



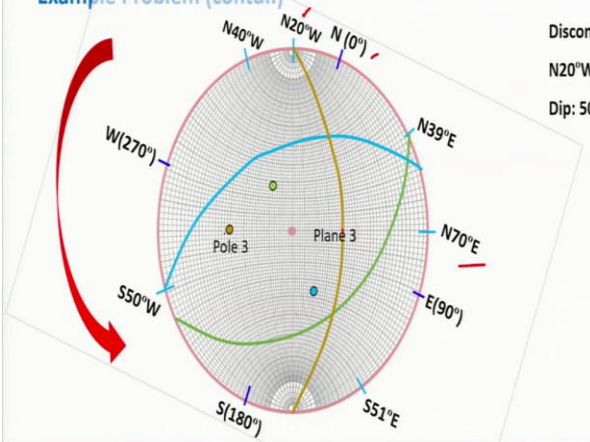
Discontinuity plane 2: Strike S50°W; Dip direction: N40°W; Dip: 40°

Example Problem (contd..)



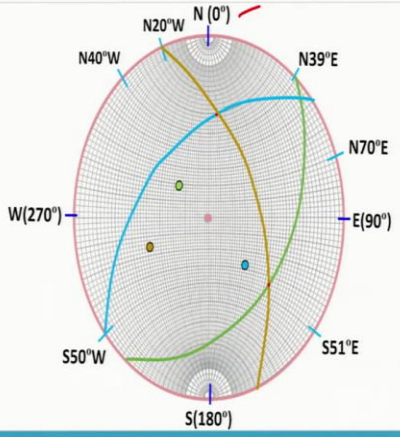
Discontinuity plane 3: Strike N20°W; Dip direction: N70°E; Dip: 50°

Example Problem (contd..)



Discontinuity plane 3: Strike N20°W; Dip direction: N70°E; Dip: 50°

Example Problem (contd..)



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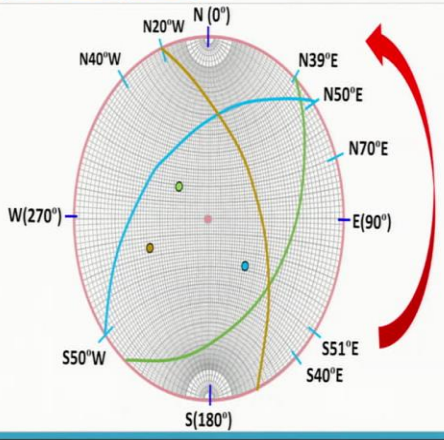
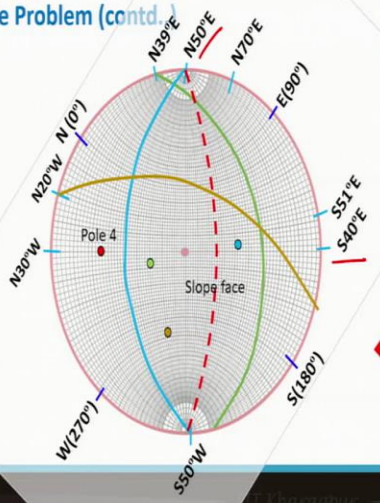
Example Problem (contd..)



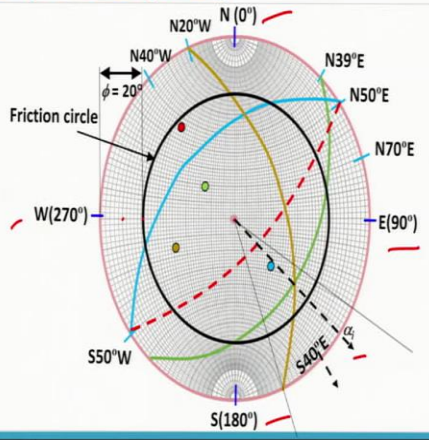
Slope face: Strike N50°E; Dip direction: S40°E; Dip: 65°

Example Problem (contd..)



Slope face: Strike N50°E; Dip direction: S40°E; Dip: 65°

Example Problem (contd..)



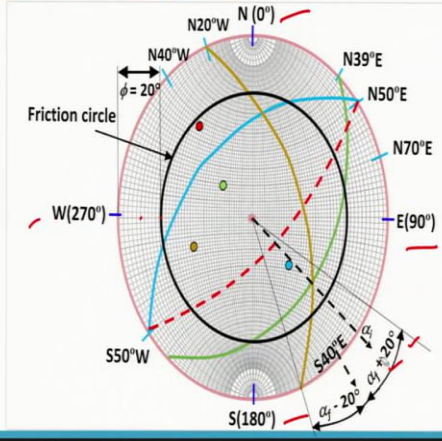
Slope face: Strike N50°E; Dip direction: S40°E; Dip: 65°

Angle of internal friction = 20°

Conditions of failure

- $\psi_f < \beta$
- $\psi_f > \phi$

Example Problem (contd..)



Slope face: Strike N50°E; Dip direction: S40°E; Dip: 65°

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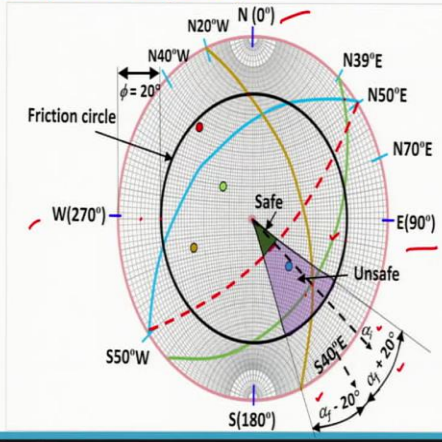
Example Problem (contd..)

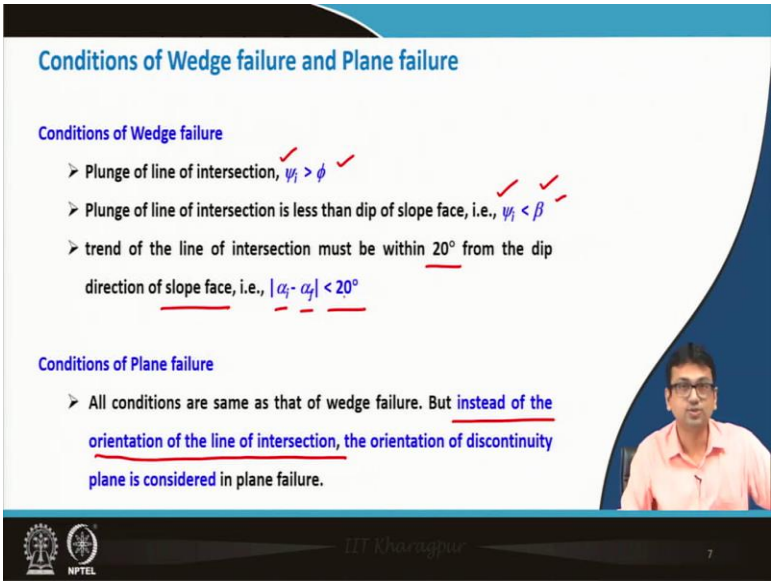


Slope face: Strike N50°E; Dip direction: S40°E; Dip: 65°

Angle of internal friction = 20°

Conditions of failure

- $\psi_f < \beta$
- $\psi_f > \phi$
- $\alpha_f - 20° < \alpha_f < \alpha_f + 20°$



So, this is nothing but the stereonet we know and have just now discussed that using that great circle as just now I have shown you can obtain this. So, what you have to do first like north, east, south, west they are nothing but 0°, 90°, 180°, 270° that is mark.

Now, the centre is marked where actually you will place the stereonet over that you will place a tracing paper and there you will mark the centre and we will pin this point.

And then this is the periphery suppose you will mark a dip line to indicate the periphery using red line. So, this is the one, now with this we have to do everything first discontinuity plane what is given strike is N39°E dip direction is S51°E and dip is 30°.

So, basically we can mark over here like this, you see this is nothing but N39°E. So, it is actually very simple. So, you can very easily identify where 39° is coming actually. You can see basically these are the actual 10, 20, 30, 40 and these individual distances are nothing but 2°. So, half of that so, here 40 and here it is 38 between these two are 39.

Similarly, here S51°E is also marked now what we have to do we have to rotate it you have a pin placed over here. So, you can very easily rotate your tracing paper. So, now, how would you will rotate you will take N39E at the this actual north position you see, you have taken it here and you see because of that this has shifted over here. So, as a result of that this will come over here now, it is stated the dip is 30°. So, you see this is 10, 20, 30. So, this point you can mark and through this you can the great circle passing through this line you will so, let us mark with a green colour

line. So, this is nothing but my plane 1 in this stereo net. So, this is the stereographic projection of plane 1 and the pole will be obviously 90° apart from here.

So, you see it is 60 on here 70, 80, 90 you see so, you can get your pole 1. So, similarly, we can get we can again rotate means rotate it clockwise and we can again north is taking its original position and actually in the tracing paper it will look like this basically. Now, the discontinuity plane 2 where the strike is this dip direction at this and dip is 40°.

So, let us mark over here you see strike dip direction. Now, what I will do I will rotate it and take the S50W over here and you see this is coming over here. Now, it is given dip is 40°. So, basically you see 10, 20, 30, 40 so, we can mark over here and you can use this suppose the blue colour for this great circle you will mark with suppose this blue colour and once that is done you can identifying your pole 2 also. So, this is nothing but plane 1 and pole 2.

Now again you will rotate it counter clockwise to bring north at its position and now it is looking like this you see there is an intersection we can notice over here so these two planes are intersecting at some point. So, third one is this. So strike N20°W and dip direction N70°E and dip is 50 °.

So, now this and this we have marked. Now again we will rotate it, strike is this N20°W. So,we will rotate it and we will take it to see north it has come to north and north has shifted over here. So, now this you will come over here your dip direction. So, now it is dip is 50 °.

So that means here this is like 10, 20, 30, 40, 50. So, through this point, you will mark this great circle with suppose brown colour. So, this will give us the orientation of the plane 3 and again you go this along this line from east to west you go 90 ° apart so you will get your pole 3. Then again rotate counter clockwise and take north at its original location. So, three planes we have identified now what we can see there is some intersection there is some intersection.

So, plane 3 is actually intersecting with both plane 1 and plane 2. Now, what is stated that the slope face slope face for this strike is N50°E dip direction is S40°E and dip is 65 °. So, now if you rotate it counter clockwise so it will go like this and you see, the strike is now at the north location and as expected, this dip direction is at S40°E as the original location of the east.

Now from east to west we will count this 65°. So, it is coming over here you see 65 is here and through this line through this point let us mark the great circle with this dotted red line it is marked and this is nothing but the slope face and again if we go 90 ° from here in the from east to west direction we will get the this pole. So, now this is the pole 4. Pole 4 is for the slope face.

So, now these things are done again we will go rotate it clockwise and I will bring the north in its original position east in a position south in its original position west is in its original position and all the three planes and one slope face and the corresponding poles are marked on this tracing paper.

So, now you see now the slope pace strikers and all what is given also the angle of internal friction given as 40° and the we know the condition of failure like ψ_i should be less than β and also considering like $\phi = 20$ we can draw a friction circle like black one as you can see over here. So, this is you see from here you are going 20° 10, 20 mark over here and draw a circle considering this pin you just draw the circle. This is the friction circle.

Now, again for failures ψ_i should be greater than ϕ, ψ_i should be less than β and so, this is nothing but the you see through the line of intersection if we connect the centre you will get this line and this is nothing but for this slope face. So now, this is nothing but my a i as we know and alpha i. So, now let us draw this you see there was a condition remember that just let me go back once again there.

I will show it again next also, but still I will i do not want that you should we should not have any confusion. So, basically what I mean I mean to say is this is one condition this is one another condition is alpha i minus alpha f less than mod this should be less than 20 °. So, that is what so alpha i and alpha f we have identified. So, this is alpha f alpha i now this 20 ° with respect to this 120 ° this side this side 20 ° this side 20 ° if we mark it will we can represent within these two lines.

So, you see alpha f minus 20 ° let me maybe delete these things otherwise so, alpha f minus 25 alpha f plus 20 and this is alpha i. So, clearly we can see alpha i is here falling between this these two lines. So, that is what written over here. So, this is the third condition. Now, also what we can see that only other two intersections are not falling within these two ranges that is also we can see also we can see that this plane this green, green one we can see that this is also means

falling over here means basically now, if we mark this region this is nothing but my safe region if something some falling in this region safe now other thing most important thing is this violet colour this is the called as the unsafe zone.

See here all these three conditions are satisfying actually getting that is getting satisfied. So, what we can see over here that ψ_i is less than beta. So, this one is less than my beta angle because this is my for slope face this is so it is here ψ_i is greater than ϕ. So it is this is up to 20. It is more than 20 is this one obviously because you see, this is falling inside means towards the centre of the, this stereo net. So, obviously this angle is more than ϕ value and also this is also getting satisfied.

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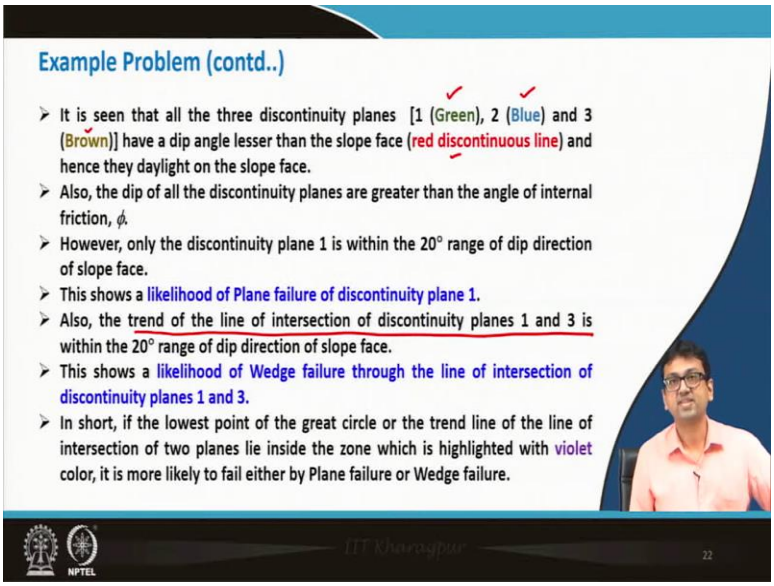

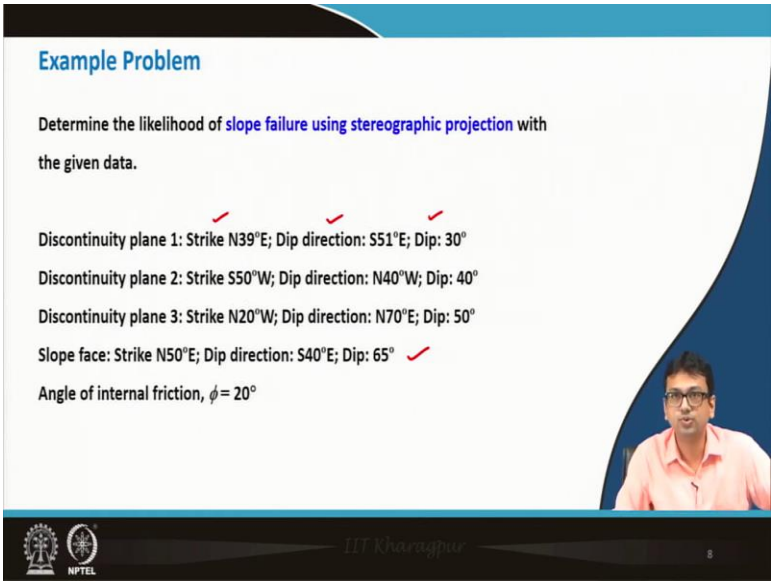

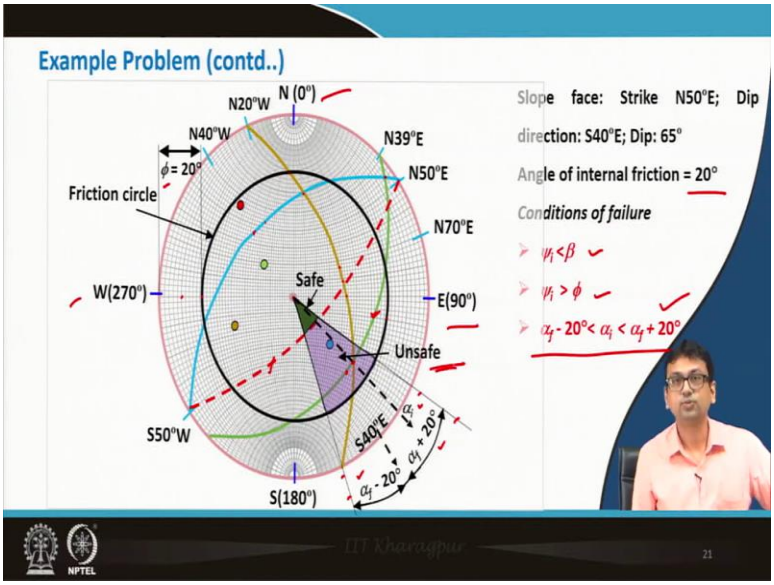

So, now from here what we can understand I just have listed over here. It is seen that all the three discontinuity planes number 1 is green one number 2 is suppose blue one and number 3 is brown one have a dip angle lesser than the slope face the red discontinuous line and hence they daylight on the slope.

So, they will be like visible to the surface i.e., slope face. So, what it is stated that green, blue and brown all these three discontinuity planes have dip angle lesser than the slope. So, obviously that we can clearly see from here also we know those things because if we again if we go to go back to the question, main question and so, what was there you see this was 65° whereas, these, these is 30, 40, 50° obvious less than that as also from this diagram also you can understand that you see this is, this one obviously quite far away from the centre this is also far away from the centre this is the far away but as compared to this line.

So, that is why it is satisfying the this that is why it is written over here now, second one is also the dip of all the discontinuity planes are greater than the angle of internal friction. So, angle of internal friction was 20°. So, obviously, that criteria is satisfying now, however only the discontinuity plane 1 is within the 20 ° range of the dip direction of the slope face. So, that is true because you see only this one is actually falling in between these two lines.

So what we can see or tell is that they show the likelihood of plane failure of discontinuity plane 1, but discontinuity plane 2 and 3 will not have the plane failure i.e., there is no chance of plane failure for plane 2 and plane 3 but there is a likelihood of plane failure of discontinuity plane 1.

Now, regarding the wedge failure, the trend of the line of intersection of discontinuity plane trend of the line of intersect discontinuity plane 1 and 3 is within 20° range of the dip direction of the slope. So, basically again let us go back there. So, you see this what I was telling, that the trend of this line α_f is falling within these two ranges. So, it is satisfying.

So, whereas, this intersection or this intersection, they are not satisfying this criteria. So, the intersection line between the, our plane 1 and plane 3 brown one. So, you see plane 1 is green plane 3 is brown. This shows a likelihood of wedge failure through the line of intersection of the discontinuity planes 1 and 3.

So, now in summary or in short it can be stated that if the lowest point of the great circle or the trend line of the line of intersection of two planes lie inside the zone which is highlighted with violet colour it is more likely to fail either by plane failure or wedge failure. So, this is what we can clearly tell from this study or after solving this or doing this stereographic projection this one we can recommend.

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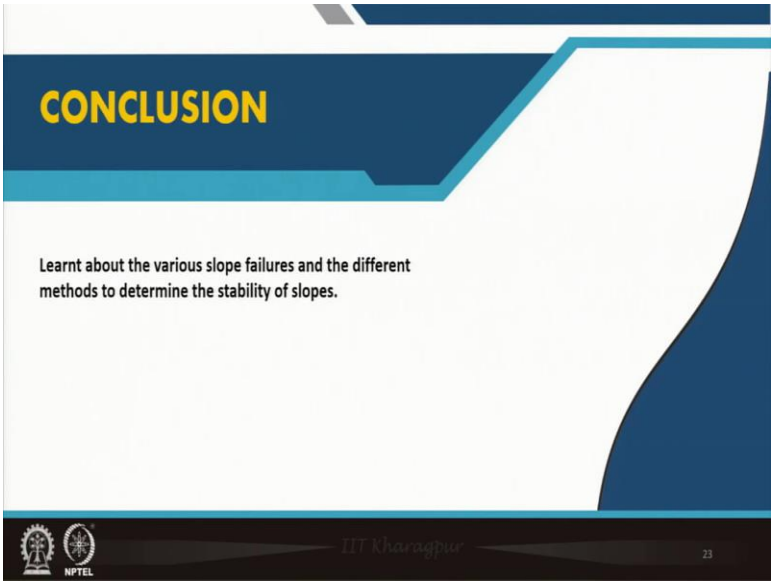

So, in conclusion, we can say that we have learnt about the various slope failures and the different methods to determine the stability of slopes in last 4 lectures and today we have learnt about the stereographic projection to find out the likelihood of the slope failure. With this, I will conclude today's lecture. Thank you.