Rock Engineering
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Lecture-09
Application of Graphical Representation of Geological Data

Hello everyone. In the previous class, we saw that how can we determine the intersection of two planes, then how can we determine the angle between two lines and how we can make the use of this stereo net for the graphical representation of the geological data. So, today, we will extend our discussion beyond that and we will see some of the application areas of graphical representation of the geological data.

That how this presentation is going to be helpful as an engineer to us, how this information is going to be useful in the analysis maybe of slopes, maybe of tunnel or maybe have foundations. So, today, we will see those applications and the special emphasis will be there on the slope stability analysis. And as this course progresses, we will see one by one chapter wise that how the representation, that is the graphical representation of the geological data helps us in the analysis of various structures, various application areas.

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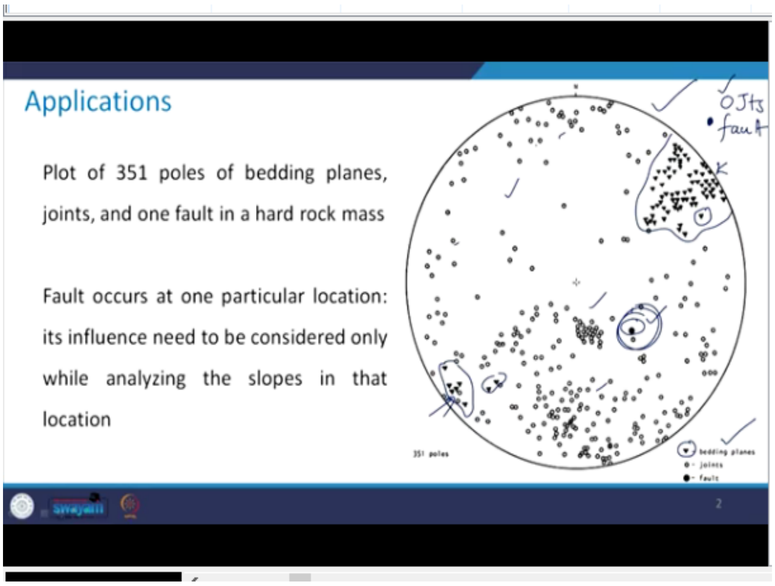

So, you see that, in this picture plot of 351 poles of bedding planes, joints have been shown. And there is one fault in the hard rock mass, that also has been shown. In the previous classes I mentioned to you that a plane can be represented in this graphical form with the help of either a great circle or a pole. So, you see that in this figure, bedding planes and joints, which are all like planes. So, these have been plotted with the help of poles.

So, you can see that three types of legions are there in this figure. One is this solid triangle, that is this one, which is representing the bedding plane. Then the circular one, which is for the joints and the solid circle, which is for the fault. Have a close look to this figure. You will see that mostly these solid triangles, they are here in this zone and some are lying here, here and then here.

There is only one fault in the hard rock mass, which is here at this location. And then you can see that joints are all over the places that means here, here, everywhere these circles that is joints these are there. Now, how have we plotted these? So, in the field you go do the exploration, note down, what is a dip, dip direction with the help of compass. Then come back to the lab or the drawing studio. Plot all that data on this stereo net and you will be able to get this type of plot. Or this type of graphical representation of all that geological data that you collected in the field.

What next? Next comes is the analysis. We will see that how these are helpful. So, as I mentioned bedding planes are here in this zone and some are here in this zone. There is only one fault and joints are all around. So, as far as the fault location is concerned, we know now, what is the location of the fault? Now, let us say I need to analyze a slope in this nearby area, then only I have to bother about this fault otherwise not.

Let us say, I have to analyze a slope, which is there say, somewhere in this area, in this zone. No fault is there. So, why should we bother about that? So, that is how the graphical representation of this data helps us in identifying the analysis part of various structures. So, right now, we will be discussing mostly about the slopes, but then we will discuss these things with respect to tunneling and foundations on weak rocks as well.

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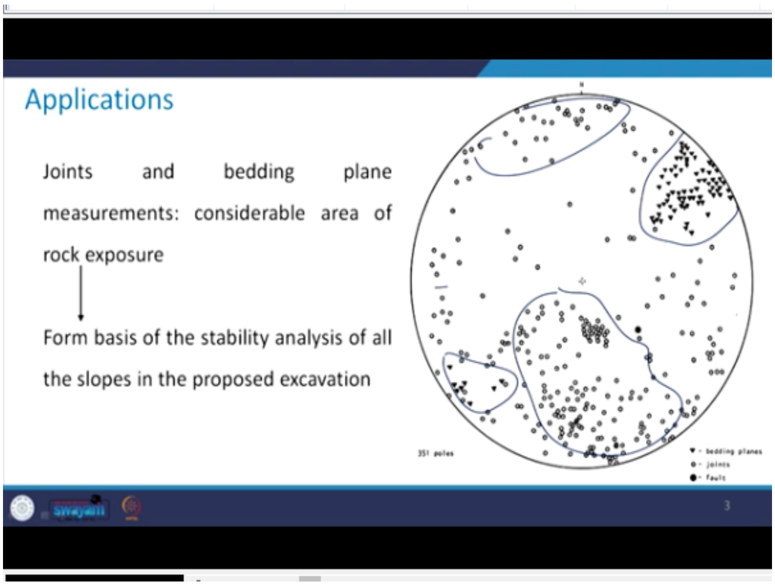

As I mentioned joints and these are the bedding planes here and, in this zone, and joints are everywhere. So, all joints are scattered throughout in the whole area. So, basically wherever the concentration of these planes is there or wherever we need to analyze the slope, accordingly, we will go ahead with the analysis. You can see that, in this figure joints and bedding planes are there in the considerable area where the rock is exposed.

And this forms the basis of the stability analysis of all these slopes in that proposed excavation. That means, that whole area has been mapped on to this stereo net. And based upon these geological structures, their concentration and where we are planning to go ahead with any kind of excavation, maybe for slope stability analysis, for tunneling purpose or for foundations on the rock mass accordingly, this data will be helpful to us.

Now, let us see with respect to the slope failure mechanism and kinematic analysis of these slopes, how the graphical representation of the geological data can be helpful to us? Now, before we go ahead with respect to this, let us try to learn about some of the terms which we will be using quite often. So, let us learn about them first.

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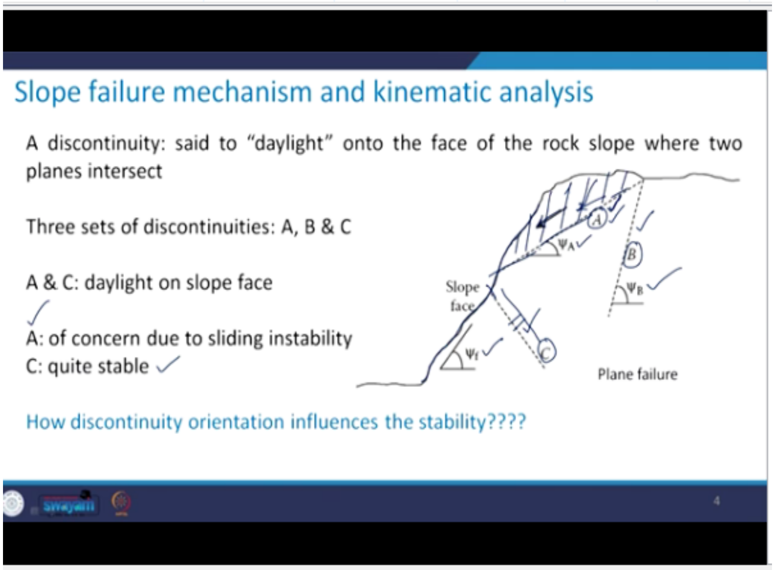

So, basically, discontinuity is said to daylight on to the face of the rock slope, where these two planes intersect. So, you focus on this figure, this is what is your slope face and it is making an angle of ψ_f with the horizontal. This means, what that the plane of the slope or the slope face has a dip of ψ_f. Can you recall the definition of dip and dip direction that we discussed in some of our earlier classes? So, it is the angle that is made by the horizontal.

So, basically here ψ_f is giving you the dip of the slope face. You can see the three dotted lines first, second and this is the third one. These are representing three sets of discontinuities and we have named it there as A, B and C. Now, this set A, that is discontinuities set A has a dip of ψ_A, again, same definition angle with a horizontal, similarly, for the discontinuity set B the dip is ψ_B, that this discontinuity A, that is this dotted line.

And the discontinuities C that is this dotted line, they intersect the slope face here and here. So, we can say that these discontinuities set A and C, they daylight on the slope face. This A discontinuity is of concern due to the sliding instability. You see what will happen, the mass of the rock which is there on top of this discontinuity, this means that this mass. This will have a tendency to slide in this direction alone, that this discontinuity A.

As far as that discontinuities C is concerned, it is quite stable. Because you see that, although it is daylighting the slope face, but you see the orientation of this discontinuity, which is like this. So, this will not have any harm to the stability of the slope. So, we can say that this discontinuity C is quite stable as far as the sliding instability is concerned of this slope face. This discontinuity A is crucial.

Now, the question comes for which we have to look for the answer that how this discontinuity orientation is going to influence the stability of this slope face in what manner? We can say that it is not safe, but we need something mathematical to decide why it is not safe? This kind of failure where the rock mass above the discontinuity has a tendency to slide along that discontinuity, that kind of failure is called as plane failure or planar failure of the slope.

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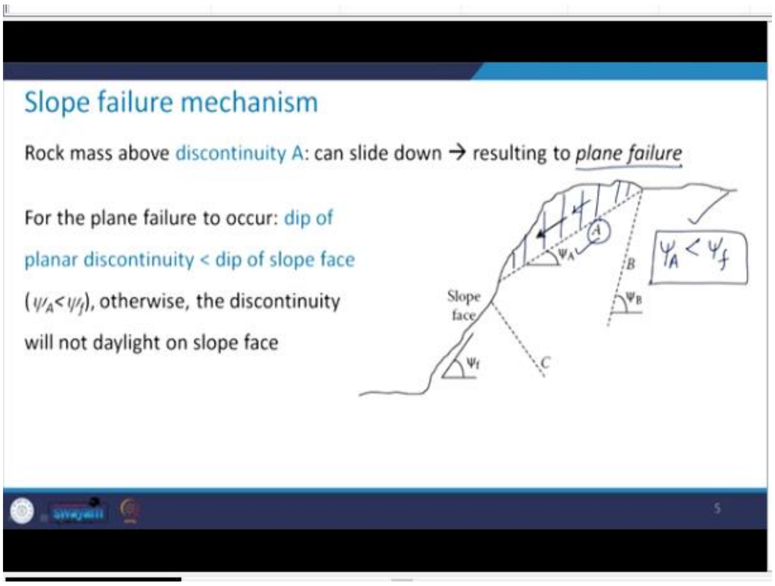

Take a look here once again. So, as I mentioned rock mass which is above this discontinuity that is this rock mass. It can slide down in the direction of this arrow and that would result to plane failure. Now, there are some conditions based upon dip and dip direction of slope face. And the dip and dip direction of the discontinuity along which there is a probability that the mass can slide down.

So, based upon the relative values, one can decide whether this mass will finally slide or not. So, there are few conditions, let us see what are those. So, the first condition is that dip of the discontinuity, what does that mean? That is ψ_A, that is dip of the discontinuity we are calling it as ψ_A, it should be less than the dip of the slope face, that means it should be ψ_f, why I am writing it as f is face okay.

Otherwise, if this condition is not satisfied, then this discontinuity A, which I am showing here will not daylight on the slope face and therefore, the probability of sliding down of the rock mass above this discontinuity will not be there. So, for a plane failure to occur, this condition has to be satisfied.

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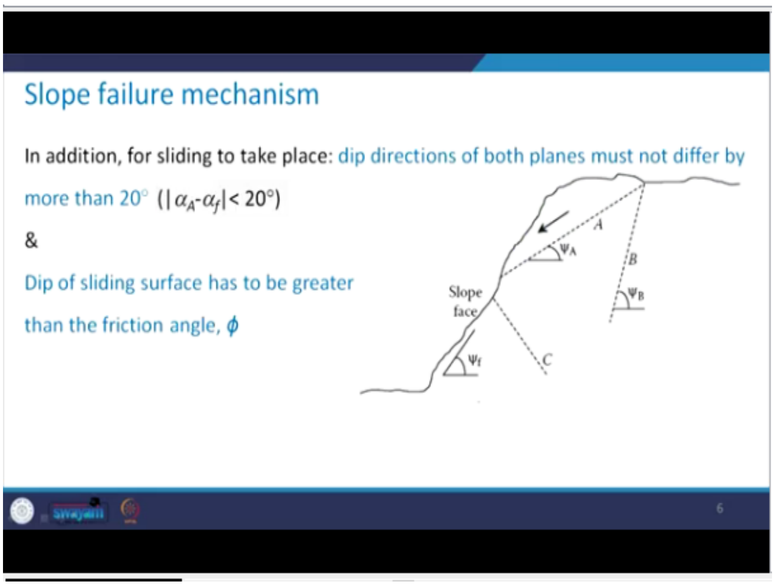

Additionally, there are few more conditions. So, you see that the next condition is that dip directions of both the planes, that means, slop surface and discontinuities. So, whenever I am saying both planes with the context of the plane failure that means, essentially, I am talking about the slope face and the discontinuity plane along which the failure will occur. So, the dip direction of both the planes they must not differ by more than 20°.

So, that means the difference between them mod of the difference between them that should be less than 20°. So, look here I have mentioned it in an expression form that is, $\alpha_A - \alpha_f$ because it is the dip directions and dip direction, we are representing by α. So, this condition is going to be $|\alpha_A - \alpha_f| < 20°$. So, this condition should also be satisfied.

So, along with that the next additional condition is that dip of the sliding surface should be greater than the friction angle. Now, that friction angle is that of the slope face, this rock mass friction angle we can find out and that is that is dip of the sliding surface means what, $\psi_A > \phi$. So, we have three conditions with respect to respective orientation of slope face and the discontinuity respective depth directions of slope face and the discontinuity.

And respective magnitude of dip of the sliding surface and that of the friction angle. So, if either of these three conditions is not satisfied, then the planar failure will not take place. So, these are, I mean, for plane failure. Now, you see here since, we have not talked about this discontinuity B.

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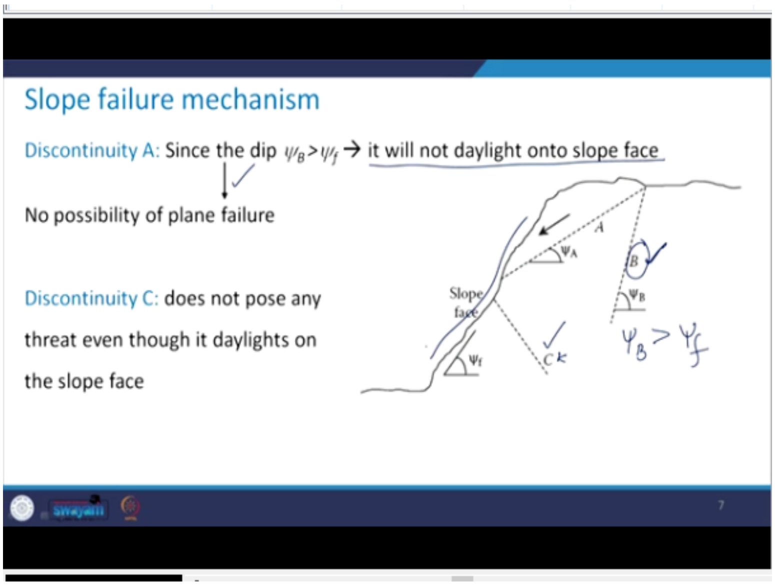

Because we said that okay, A is crucial for the planer failure, C will not have any effect it is stable. What about this B? So, can you see here? Look at their relative magnitude of their orientation. It looks like that in this case your ψ_B is more than ψ_f and therefore, this discontinuity B will not daylight on to the slope face and what does that signify? This signifies that there will be no possibility of plane failure along this discontinuity B.

And as I already mentioned, that even though this discontinuities C, it daylights the slope face, but it will not pose any threat towards the stability of this slope. So, this is how one needs to look at the relative orientation of these discontinuities along with the orientation of the slope face, in order to decide whether a particular type of slope failure can occur or not. So, here we discussed about one type of slope failure mechanism, which is the plane failure.

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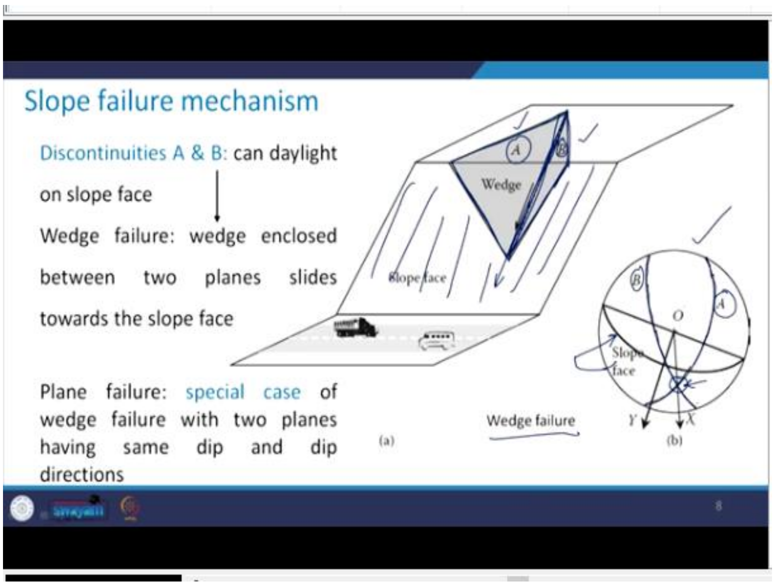

There are few more. So, let us have a look. So, the next one is, there can be the occurrence of the wedge failure. Now, think about the two discontinuities or two discontinuity planes, see here this shaded portion. So, this one plane is this plane, that is, I say that it is the discontinuity plane A and this is the next another one which is B. Now, wherever they intersect each other of course, the intersection of the two planes as we have discussed in the previous class is going to be a line.

So, both these discontinuities A and B, you see, they are daylighting this slope face which is this face. This is the slope face. So, they are daylighting both of these are daylighting the slope face. What do we understand by the wedge failure? So, you see both the discontinuities are there and whatever is the wedge that is being formed here, you see, like this, it will have the tendency to slide along this line of intersection.

So, this will be sliding towards the slope face. So, this is what is called as the wedge failure. See in case of the plane failure, it was only one discontinuity which was there along which the sliding was taking place. But here what is happening is you have two planes and whatever is the wedge that is formed in between these two planes, that whole wedge will have the tendency to slide towards the slope face. So, this type of failure is called as wedge failure.

Now, the plane failure is a special case of the wedge failure. So, let us say that in case of the wedge failure you have these two planes A and B. Now, let us say that these two planes, they have same dip and same dip direction, then what will happen, that this plane failure will become the special case of the wedge failure. So, let us see how do we analyze this?

Take a look at this stereo plot that has been shown and connected with our discussion in the previous class. So, you see that wedge or the discontinuity A has been drawn with the help of a great circle in this figure like this one. See you traverse along this great circle and this is what is representing the discontinuity plane A. The second discontinuity plane is this plane B, which is this great circle.

And this great circle which is shown by little thicker curve great circle that is for the slope face. So, you see both of these planes, they are intersecting at this particular point. So, I mentioned to you that line in 3D will be shown as a point in 2D. So, the line of intersection of these two planes A and B which is this line, that is shown by a point here, where both these great circles they are intersecting each other.

Now, if we join this point with the center that means, if we draw a radial line through this point, so, this vector OX you see this OX, that is going to give us the direction of the sliding, let us take a look once again.

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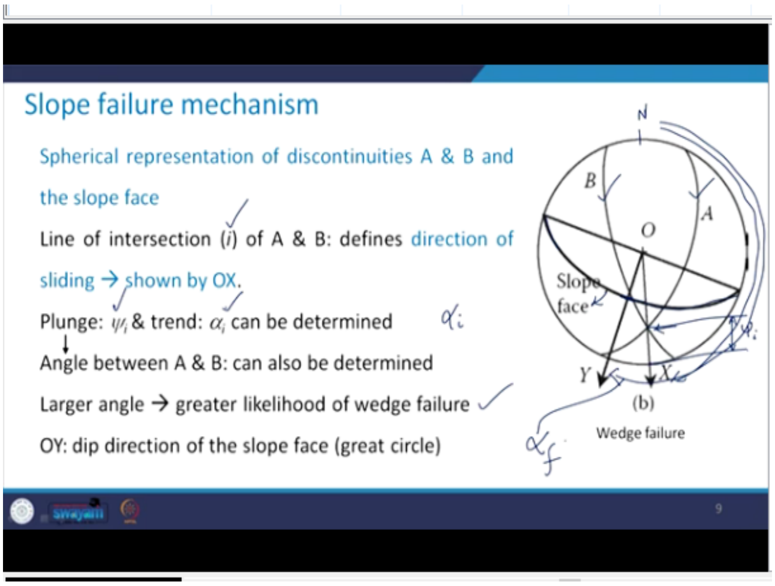

So, you see that a spherical representation of the discontinuities A and B and the slope face. I have already mentioned that this is the great circle which is showing the discontinuity A. This is the great circle showing the discontinuity B. This dark one that is this one is showing you the slope face and wherever these are intersecting. This is the line of intersection of these two planes. That means, I am representing that line of intersection, let us say by a subscript of *i*.

Now, this vector OX you see in this direction that will define the direction of sliding. That means both whatever is the rock mass in between that wedge, it will slide along this vector or this line OX. Now, the plunge and trend of this line how can we determine that? So, you see that you can determine the plunge in this manner, like from the extreme point to this point, whatever is this angle that you are going to get us ψ_i.

Now, if this is what is the north direction. So, when you have from the north move in the clockwise direction and whatever is this angular distance that is going to give you this trend which is α_i. Remember we discussed that plunge and trend of a line is similar to dip and dip direction of a plane respectively. So, that is how we can find out the trend and plunge of this line of intersection.

Please take a note that here because it is the line of intersection, so, I am using a subscript *i* with both of these, keep that in mind. Now, this angle between A and B also can be determined. We have discussed that in the previous class. Now, larger the angle between the planes A and B and greater will be the likelihood of wedge failure. That you need to keep in mind. Always this condition will be there.

Now, see, look at this slope face and here it is the maximum curvature is there. So, if we try to draw a radial line through this maximum curvature that is going to give me the dip direction of the slope face. So, how I will determine? So, you see from here you again move in the clockwise direction up to this and this is what is going to give you the dip direction of the slope face.

So, how are we representing the dip direction by α and because it is for the slope face, that is I am writing as α_f, using this figure, when we plot all the geological data that we had the side, that is slope face, the two discontinuities when we plot them, we can see that in which direction the wedge will likely to slide and how we can find out the trend and plunge of that direction. Now, for the wedge failure to occur, again we will have some of the conditions.

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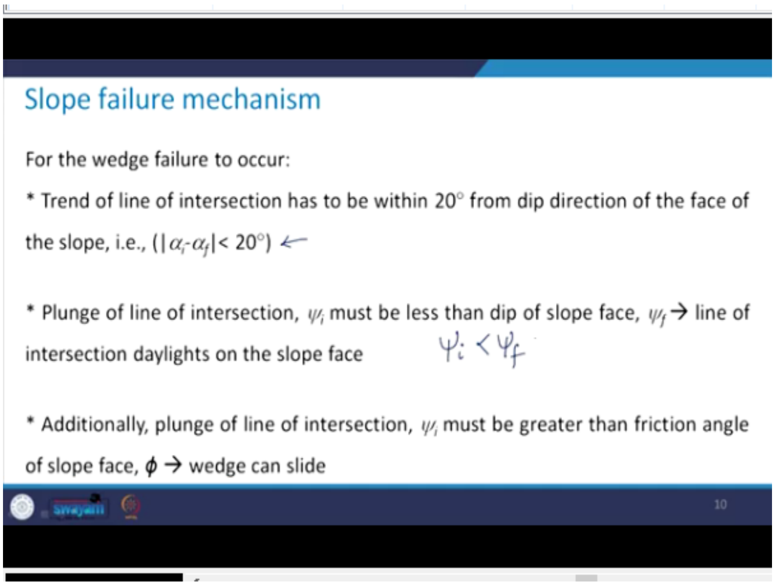

That is trend of the line of intersection that has to be within a 20° from the dip direction of the face of the slope. That is mathematically, this is how it is to be represented. Plunge of the line of intersection that is ψ_i must be less than ψ_f. In this case only the line of intersection, *i* will daylight on the slope face. Now, the question is if it does not daylight on the slope face, then what will happen?

Obviously, in that case, the wedge will not slide, the wedge which is being formed between the two discontinuity planes A and B which we have taken if this condition is not satisfied that wedge will not slide. Additionally, what is the third condition? That is plunge of the line of intersection which is the ψ_i, that must be greater than the friction angle of the slope face. That is the wedge can slide in that case.

Because that will help the wedge to slide. Now, the question is if even one condition of these three is not satisfied, the wedge failure will not take place. Please keep this in mind that for the wedge failure to occur each and every condition of these three which has been shown in this slide, all these three conditions should be satisfied. So, there is nothing like this or this or this. It is this and this and this, all the three has to be satisfied.

Now, these conditions if you have noticed, these are same as that of the plane failure only difference is in case of the plane failure, we talk about the orientation of the discontinuity. While in case of the wedge failure, we talk in terms of the orientation of line of intersection. So, this is how we can decide whether the wedge failure is going to take place or not. So, you see how useful this graphical representation of the geological data is for the kinematic analysis or the slope failure mechanism for the different types of slope failure to take place, how this graphical representation of geological data is important.

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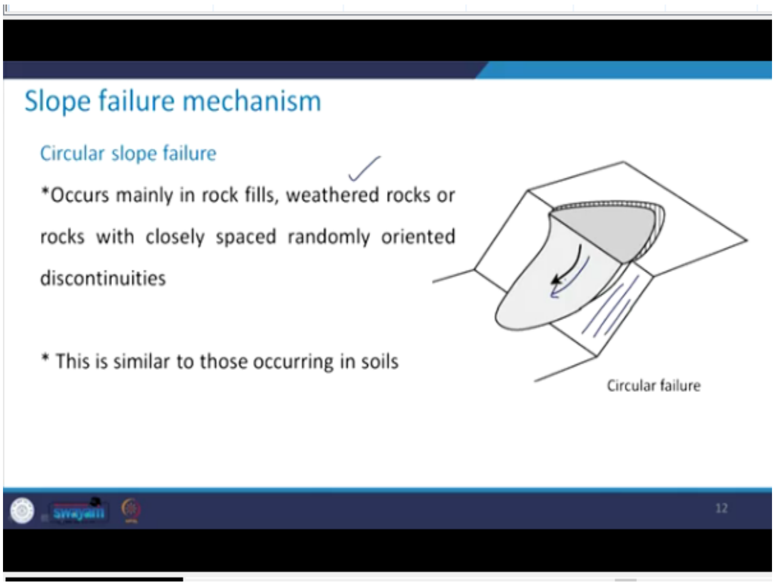

Now, the next type of failure which can occur in case of the slope, that is circular failure, which occurs mainly in the rock fills and the weathered rocks or rocks with closely spaced randomly oriented discontinuities. And this is very much similar to that which is occurring in the soil. So, you see, there is a three-dimensional picture which is shown here. This is the slope face and see in a circular fashion, this mass is coming down. So, this is what is called as the circular slope failure.

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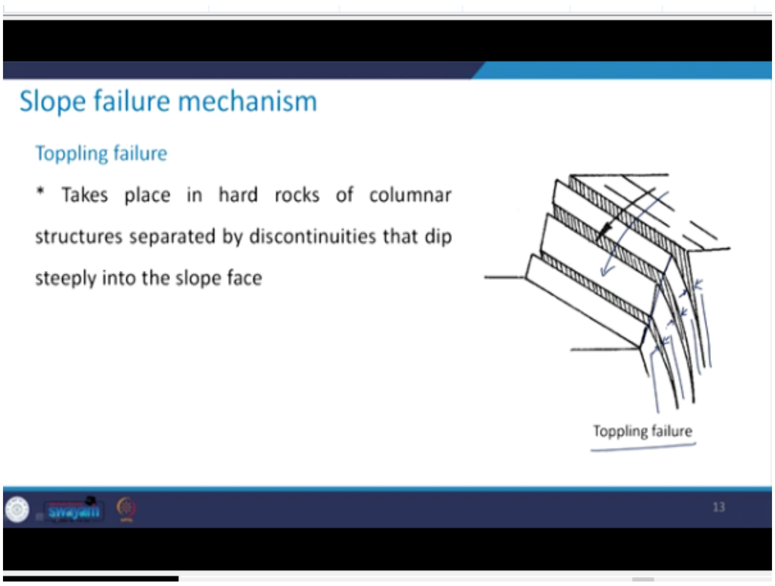

Now, the fourth type of failure in case of the slope is called as the toppling failure, which takes place mainly in hard rocks of columnar structures. That means, you see that these are the orientation is like, the dip is quite high. It is nearly vertical and if these are separated by these discontinuities, you see, these are the discontinuities and if there is a rock movement in this direction in the direction of the arrow, so, this type of failure is called as toppling failure.

And that occurs when the discontinuities or the when the rocks are of the columnar structures and they have the discontinuities which are dipping steeply into the slope face. So, you see this is the slope face and the dip is so large in this case, it is almost vertical.

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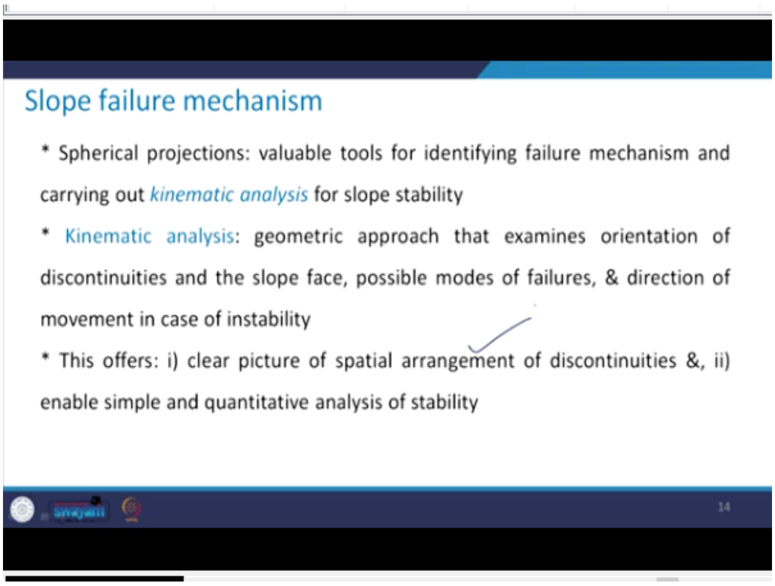

Now, let us try to see how to make use of these geological data representation in the kinematic analysis of the slope failure. So, basically these spherical projections, these are quite valuable tools in identifying the kind of the failure mechanism that may take place, whether it can be plane, it can be wedge, it can be circular or it can be toppling type of failure. And then they are helpful in carrying out the kinematic analysis for the slope stability.

The question is what do we mean by kinematic analysis? So, it is a geometrical approach using which we can examine the orientations of the discontinuities and the slope face, possible modes of failure and if there is the instability, then what is the direction of movement? So, basically the kinematic analysis it offers two things: one is the clear-cut picture of the spatial arrangement of the discontinuities.

And rather than going into very tedious mathematical aspects in a simple graphical manner, we will be able to quantify the analysis of the stability of the structure slope or tunnels or the foundations. Right now, we are discussing with respect to the slopes. Now, let us take a look at the kinematic analysis. So, first we will discuss with reference to the plane failure. Now, in case of the plane failure what is happening? You have the slope face. So, that is being represented by a great circle.

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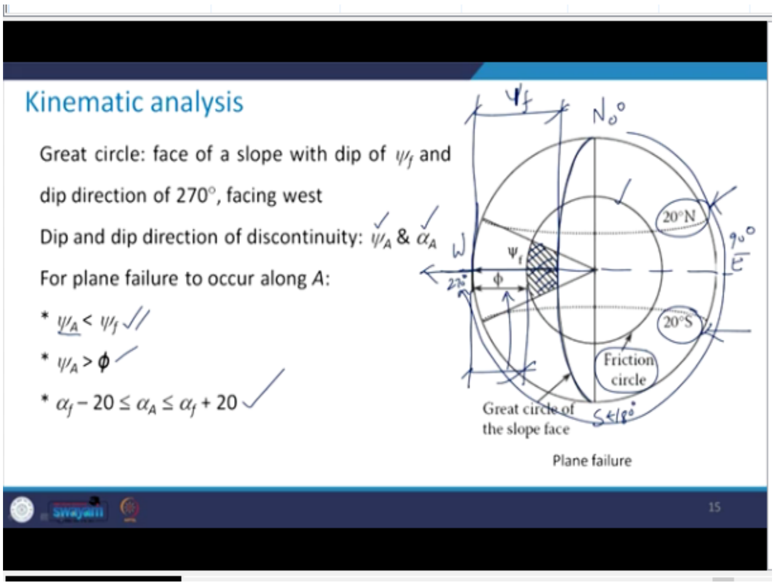

You see here like this. Now, here is the maximum point of curvature if you try to draw a radial line what is happening is, it is coinciding with this, let us say this is north, south and I extend this, this is east and then west and if you remember the stereonet, so, here it is 0°, then it is 90°, 180° here and this angle is 270°. So, in this case this slope face has a dip direction of 270°.

So, you see that from here you come in the clockwise direction and here it is 270°. Now, what is the dip? How do we find out the dip? We take it from the extreme point of this circle to this great circle. So, this is what is going to give me ψ_f, which is the dip of the slope face. So, the slope face, we know the dip and the dip direction and, in this case, a particular case that we have taken, it has a dip direction of 270° facing west.

Now, dip and dip direction of the discontinuity is being represented by ψ_A and α_A respectively. As I discussed with you for the plane failure to occur along the discontinuity A three conditions have to be satisfied, what are those three conditions? That is, they have this discontinuity must be less than a dip of the slope face, which can be expressed like this that is, $\psi_A < \psi_f$.

Then the dip of the discontinuity must be more than the friction angle which is this. Now, here you see how do we define the friction angle. You can see here a circle has been drawn which is denoted as a friction circle. So, its distance from the reference circle that is extreme most part of the reference circle, that is this distance is ϕ. So, that is how this friction circle can be plotted in this 2-D plane.

Then, the third condition is that the difference of the dip direction of the slope face and that of the discontinuity should be less than 20°. So, you see that this is the dip direction of the slope face. I explained it to you that how it is we have taken a typical case. So, do that ±20°, you have 20° north latitude and 20° south latitude which is there. So, now, this is what is going to be your third condition.

You take all these three conditions on this graphical plane and find out what is the area of intersection of these. So, you see that, that area I have shown here with the help of this hatched portion. So, if the discontinuity is lying somewhere in this zone, then only the plane failure is going to occur, otherwise not.

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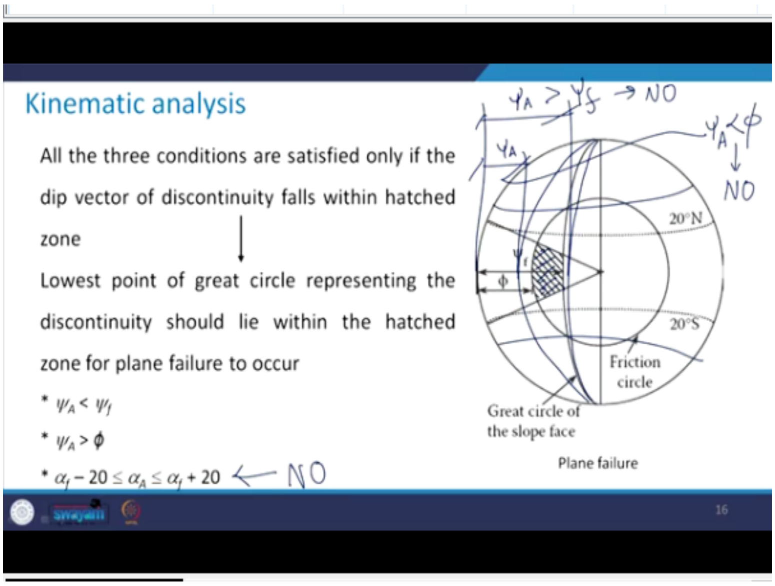

Look here, that all the three conditions will be satisfied only if the dip vector of the discontinuity, it falls within this hatched zone. Lowest point of the great circle, that is this, is representing that the discontinuities should lie within the hatched zone for the planar failure to occur. Now, take a look here in this case whether this will happen or not? So, you see, if you have ψ_A should be less than ψ_f.

So, if the discontinuity is there somewhere here in this. So, obviously, in which case ψ_A will be more than ψ_f. If this great circle of the discontinuities like this, then in that case what will happen? This will become ψ_A which will become more than ψ_f and therefore, no plane failure. So, that means, it has to be within this hatched zone. So, that is one thing.

Second thing is let us say ψ_A should be more than ϕ. Now, say the discontinuity has this kind of great circle. So, what will happen in this case? In this case this will become ψ_A and you see what will happen here, this ψ_A is less than this angle ϕ. So, what will happen? This discontinuity is not lying in the hatched zone. So, again in this case, no failure is going to take place as far as plane failure is concerned.

Similarly, let us say the discontinuity is in such a manner that it is having a dip direction either here or here. So, then in that case, this third condition will be violated and again there will be no plane failure. So, in order to satisfy all these three conditions, the discontinuity must lie within this hatched zone. If it goes here or this side or that side, top or bottom either of these three conditions are not going to be satisfied.

And therefore, the plane failure is not going to take place. Now, similarly, we take a look with reference to the wedge failure in this figure.

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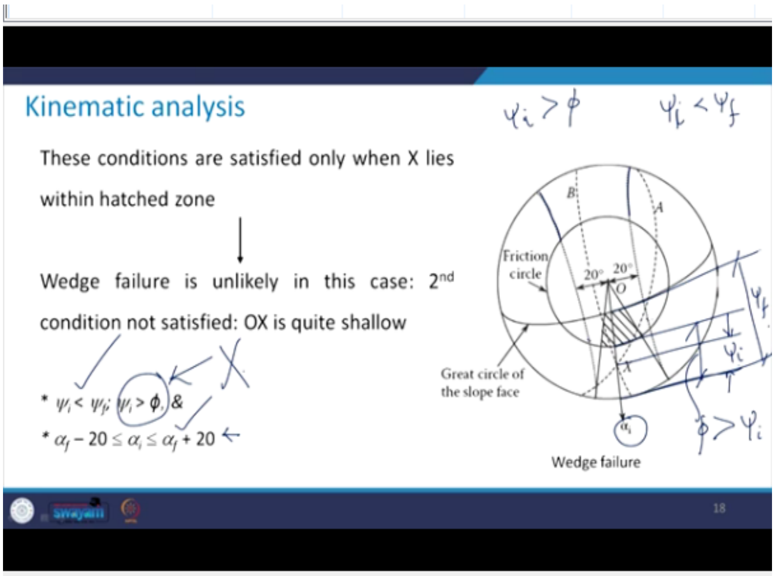

So, you see that we have two dashed great circles, which are representing the planes of discontinuities A and B. So, you see here, this is the one and this is the another one, which is here. They are intersecting at a point which is denoted by this point X, if I just try to draw a radial line, that is this line. So, this is giving me the dip direction of the line of intersection. I should not say dip direction, what should we say, we should say this is the trend.

Because in case of the line we talk in terms of plunge and trend. How I can find out the plunge of this line? See, take this perpendicular distance. So, whatever is this angle, that is going to give me the plunge of this line. And this direction is going to give us the possible direction of the sliding. Now, for the wedge failure to occur, again, the conditions are going to be the same these three conditions, except for the case that in the plane failure, we took the plane of discontinuity. In this case we are going to consider the line of intersection of two discontinuity planes, which are A and B here. Additionally, please see how the friction circle has been drawn. And this one, and how the great circle for the slope face, has been drawn here.

Now, once again, as we did in case of the plane failure, for all these three conditions to be satisfied, the line of intersection must lie within this hatched zone. See how. Take a look here, the first condition says that ψ_i must be less than ψ_f. So, here you see, let us see how it is. So, see this is what is your ψ_i. What is going to be your ψ_f? Somewhere something like this. This is what is going to be your ψ_f. So, what is happening?

This is satisfied see, $\psi_i < \psi_f$. So, the first condition is satisfied okay, now come to this condition, that is what about its dip direction? Its dip direction here is you see α_i, which is say from the north, it is this α_i. And then ±20, two latitude we have taken like this okay, so this is the first one, and this is the second one okay. Now, this α_i, in this case is lying within the zone.

So, this is also satisfied. Come to the second condition ψ_i. $\psi_i > \phi$. Now what is happening in this case? You take a look what is ϕ here. You see any radial direction. This is what is ψ_i and see here, this total is your ϕ okay, what is happening in this case? In this case this ϕ is more than ψ_i. So, this condition is not satisfied. And therefore, this particular case which I have shown in this figure, wedge failure is unlikely to happen.

Because the second condition is not satisfied, because of the fact that this OX is quite shallow. Quite shallow means that ψ_i is less than ϕ value okay. So, the second condition is not satisfied. So, wedge failure is not going to occur in this case. So, you see that how this graphical representation is helpful in identifying the mode of failure. So, it is not that we are just doing it to represent the 3-D data on a 2-D plane.

We are going to make use of this geological representation or the graphical representation of the geological data for the analysis purpose, analysis of slopes, analysis of tunnels or the foundations on the weak rocks. The only thing is we need to go to the field, collect all the geological data, plot it and then try to analyze the data in order to decide what kind of failure mode can happen. Whether the failure will occur or not, whether those geological structures, they are dangerous towards the stability of the structure which is going to come out at that site.

So, this is what that I wanted to discuss with you, with the reference to the graphical representation of the geological data. We will be taking the help of this information, this discussion, time to time throughout this course with reference to various chapters when we will discuss about the tunneling, we will make use of this.

When we discuss about the slope stability analysis, again we will come back to this, when we discuss about the foundations on weak rocks. Again, we will see that how this graphical representation is helpful to us. So, in the next class, we will start our discussion on the new chapter, that is the laboratory testing of the rocks. Thank you very much.