Rock Engineering
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Lecture - 43
Structurally Controlled Failure: Roof Failure

Hello everyone. In the previous class, we discussed about this structurally controlled failure. And I mentioned to you that the wedges can be formed in the roof or in the sidewall of the tunnel. And those wedges may fall vertically from the roof or may slide along the sidewall of the tunnel. How to carry out the analysis for this? We saw that these stereo plots can be useful to us.

If you recall some of our earlier discussion, where I explained you the philosophy of these stereo plots and then I mentioned that we will be using these as far as the application areas related to rock engineering is a concern. So, those use, we will learn in today's class. So, let us continue with the structurally controlled failure with special mention to the roof failure.

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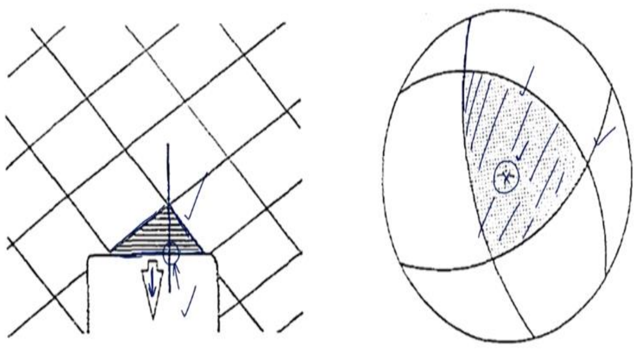
Structurally controlled failure: roof failure



Conditions for gravity falls of roof wedges (Hoek and Brown, 1992)

I mentioned to you that the wedge can be formed in the roof by these 3 discontinuity planes. And the condition that this wedge will fall in the vertical direction was that a vertical line which is this line, passing through the apex of this wedge if it is crossing the base like this, like here, in this case, it is crossing it here. This means that this wedge will have the tendency to fall in the vertical direction in this excavation.

And how the stereo plot can help us in identifying this situation, is that we draw these 3 great circles first, second, and the third great circle, which is representing these discontinuity planes. And then, this centre of this net is representing this apex. And if this is lying within this intersection zone of these 3 great circles, then this condition will be satisfied that the vertical line passing through the apex of the wedge is also within the base of the wedge.

So, I mentioned to you in the previous class that stereographic method can also be used for a much more detailed evaluation of shape and volume of potentially unstable wedges. So, this is how the representation is made.

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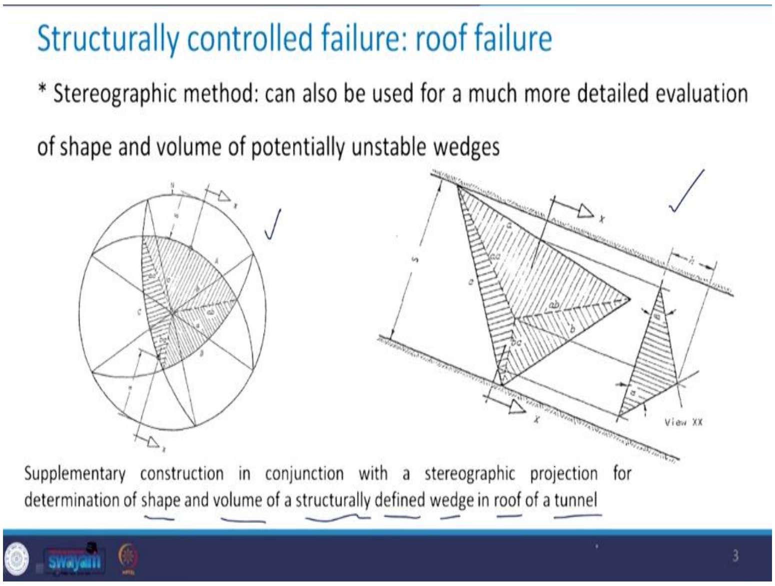

Take a look at this figure. These are giving you the idea about the supplementary construction in conjunction with a stereographic projection for the determination of shape and the volume of structurally defined wedge in roof of a tunnel. Let us learn about these in detail. How these can be constructed?

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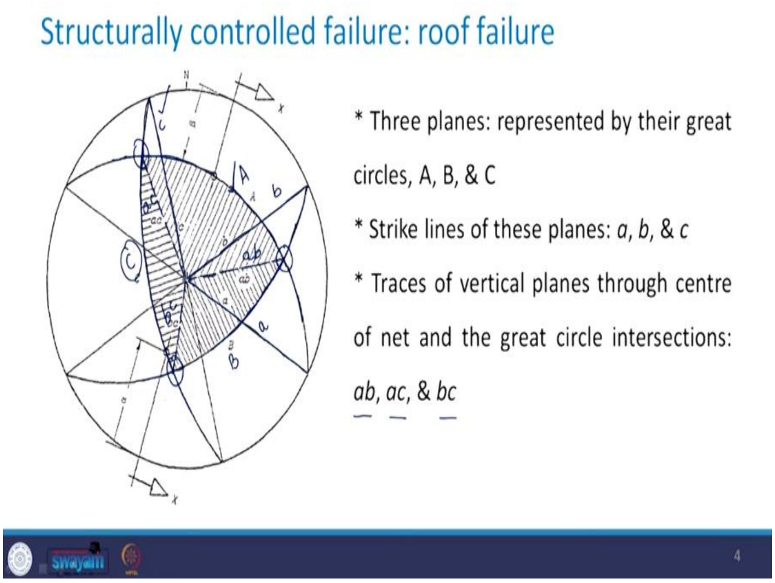

So, first we take a look at the stereographic projection. You all know that any plane. It can be bedding plane. It can be joint. It can be any plane that can be represented on the stereo plot with the help of either the great circles or the poles. So, here in this case, these 3 planes have been represented by the great circles A, B and C. So, this great circle is A. The great circle, the second one is B. And the third great circle which is this one, this is what is the great circle C.

So, this is how because we know the dip and dip direction of those discontinuity planes. Knowing these 2 quantities, we can have their corresponding great circles in such manner. Now, strike lines of these planes are being represented by small letters *a*, *b* and *c* respectively. See how? So, this was the circle *a*. And you can see that this is the strike line of the plane *a*. And this I am representing by small *a*.

This is what is your great circle for plane B. So, I joined this with the centre and this is going to give me the strike line of plane B and join this you will get the strike line of plane C which I am representing by small *c*. Now, the traces of vertical planes through the centre of the net and the great circle intersections they are represented by *ab*, *ac* and *bc*. How? Look here this is the great circle A.

This is the great circle B. Wherever it intersects that is this point we join it with the center. And this we are calling as *ab*. Similarly, this is the great circle A and this is the great circle C and this point they are intersecting each other join this with the centre and you will get *ac*. Similarly, circle B and this great circle C intersecting at this point join it and this is what you will get as *bc*.

These represent the traces of vertical planes through the centre of the net and the great circle intersections.

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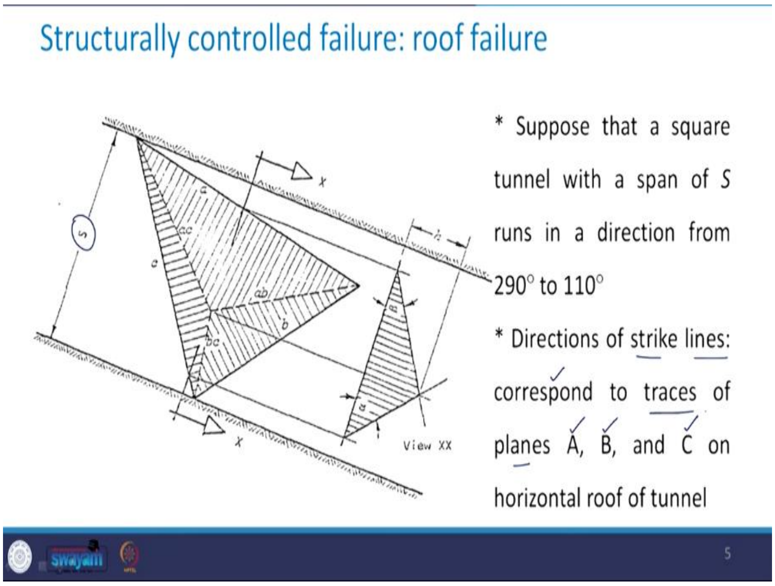

Now, say there is a square tunnel with a span of S and it runs in a direction from 290° to 110°. So, here you see the span S of the tunnel has been shown. This is the plan. Now, these directions of these strike lines, these will correspond to the traces of planes A, B and C on the horizontal roof of the tunnel. So, these traces, how these have been obtained? We have seen in the previous slide. So, let us put both the figures together in order to see that how this figure has been drawn?

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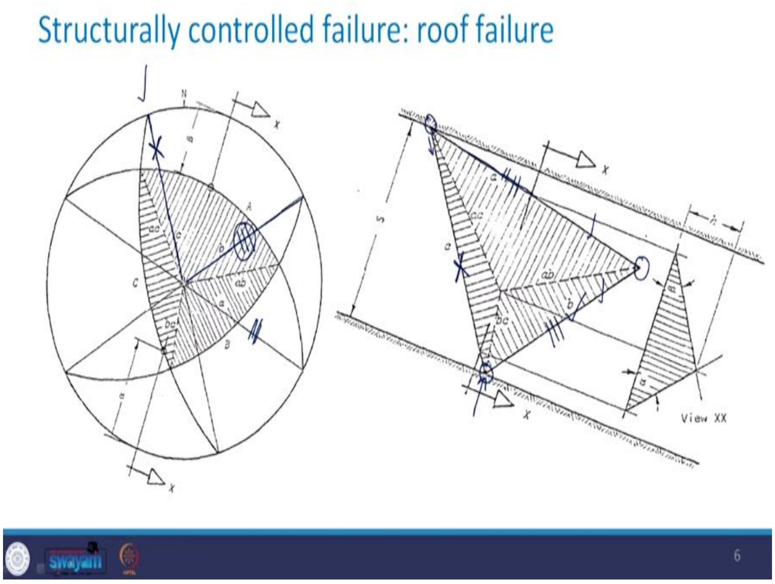

So, you see that this line here. This is parallel to the trace *a* here. Similarly, this is the strike line *b* and this is parallel to this line. This is the strike line *c* and this line is parallel to this line.

So, we take a point here, any point you can take. Then from here draw a line which is parallel to this line because the length of the line is not known. So, just keep it like that. From this point again draw a line which is parallel to this line *c* which we know already.

So, this will intersect this plan in the plan the dimension of the tunnel at this particular location. And from this point, you draw a line parallel to this line to this part of the figure. And wherever this line and this line will intersect that will give you the third point of this triangle. Now, what does this signify?

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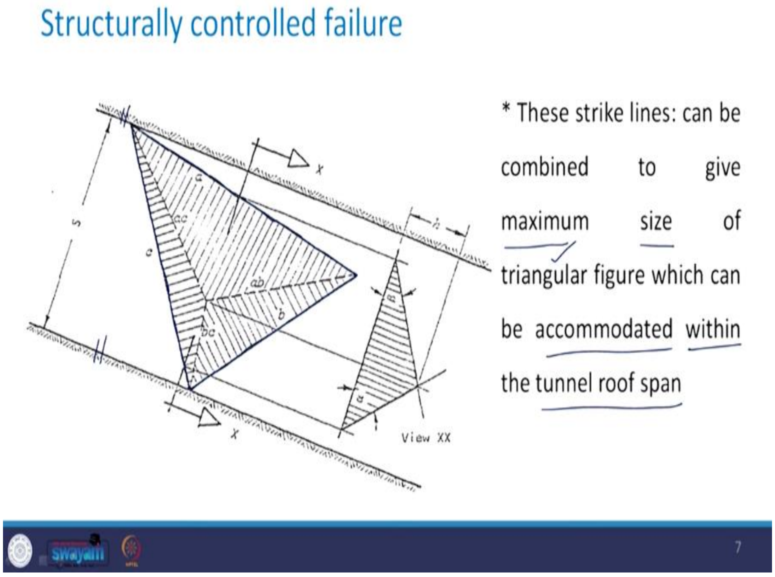

So, these strike lines can be combined to give the maximum size of the triangular figure, which can be accommodated within the tunnel roof. Now, I already explained you that how this triangle can be constructed with the help of that stereographic projection. So, we took the help of those strike lines and constructed this triangle like this. Now, this triangle represents the maximum size of the triangular figure that can be accommodated within the tunnel roof span.

Because you see that here this is one boundary of the tunnel roof in plan and this is another one. So, this is the maximum size of the triangle that can be accommodated in between these 2.

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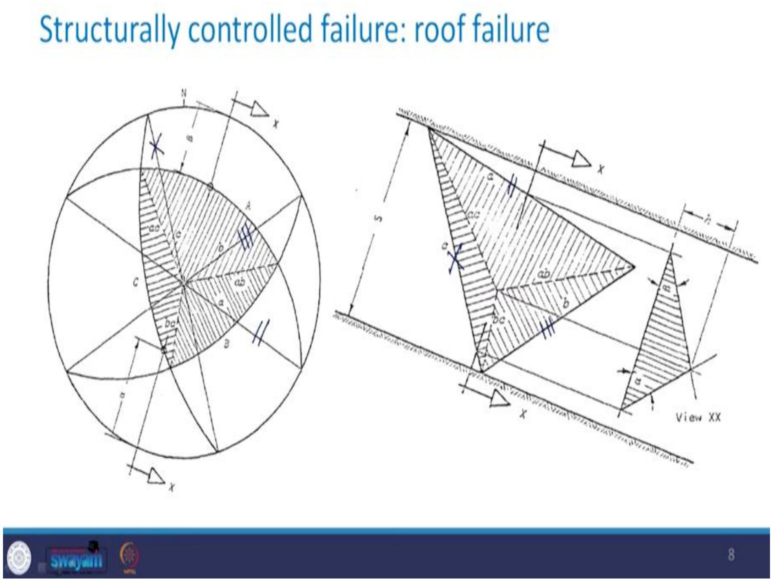

So, once again see here, this *a* is parallel to this strike. This *b* is parallel to this strike. And this *c* is parallel to the strike *c* here. And this is how this triangle is constructed. So, the plan view of the tunnel, it gives us the idea about the apex of the wedge.

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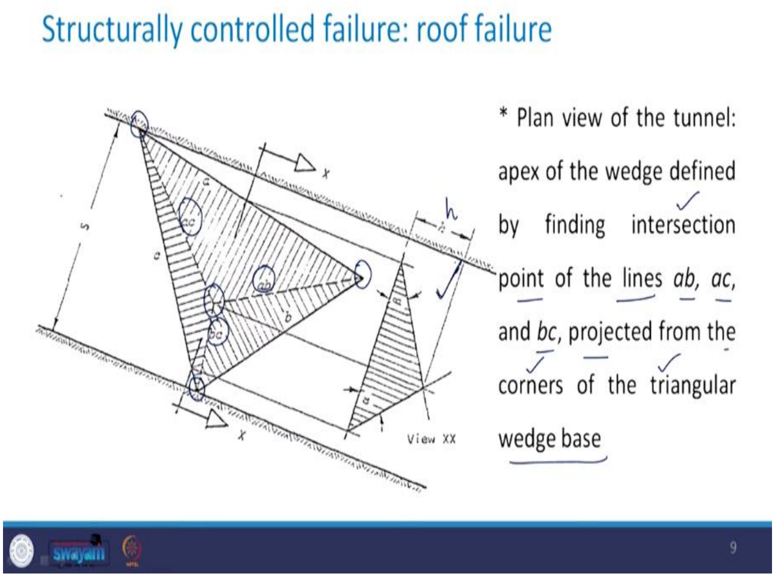

Which is defined by finding the intersection point of the lines *ab*, *ac* and *bc* which are projected from the corners of the triangular wedge base. Now, we already have obtained these triangular wedge base and 3 corners of this. These lines *ab, ac* and *bc* they can be drawn from these corners in such a manner that these lines are parallel to the corresponding lines in the stereographic projection.

So, wherever these 3 will intersect, that is going to give you the apex of the wedge. Now, in order to obtain the volume and the height of this wedge, we need to get this dimension which is small *h* which has been given in this figure. Let us see how?

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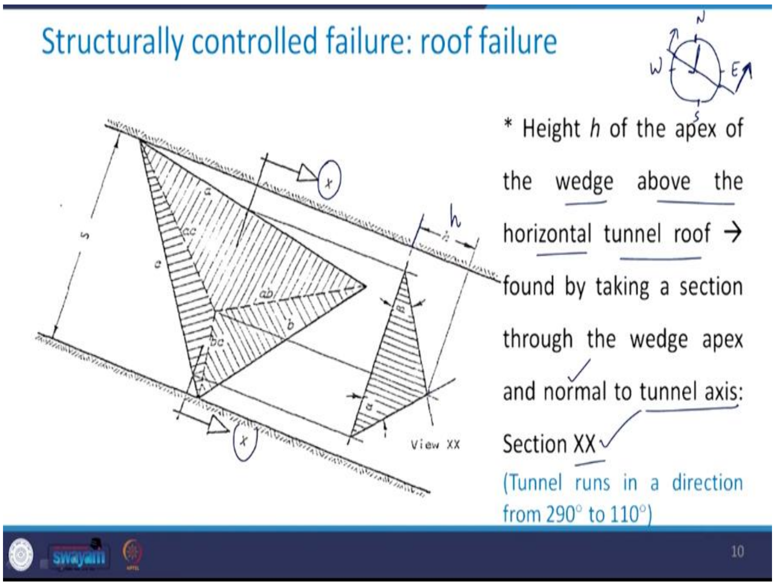

Height *h* of the apex of the wedge above the horizontal tunnel roof that means, from this point it is this is the apex. So, this is this dimension is *h*. It is found by taking a section through the wedge apex and normal to the tunnel axis, which is the Section XX here. Remember that tunnel runs in a direction from 290° to 190°. So, on the stereo net you see this was the reference sphere where this is let us say your north direction.

And this is south, east and west. So, 290 will be let us say, somewhere here and 110 will be somewhere here and this has to pass through the center. So, if it is like this, so, I take a line or a section which is perpendicular to this. So, that section we are defining as the Section XX because this is the direction of the tunnel axis and we have to take a section which is normal to the tunnel axis. So, that is what that we have taken here Section XX. So, here you can see that.

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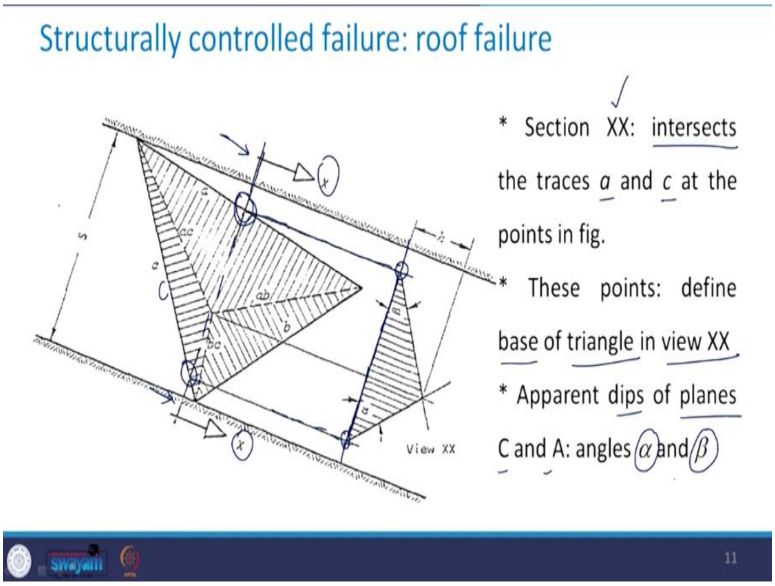

This Section XX intersects the traces *a* and *c* at these points. So, you see here this is what is your Section XX. And it is intersecting the trace *a* at this point and trace *c*, which is this one at this point. So, these points they define the base of the triangle when we have the view in this direction which is XX that means, when you look in this direction. So, you see that perpendicular to this XX direction we just project these points with the help of these projectors.

And we have a line which will intersect these 2 projectors at this these 2 points. And if you join these, this is going to define the base of the triangle in view XX. Now, these apparent dips of the planes C and A, they are given by angles α and β respectively. How to obtain these angles α and β?

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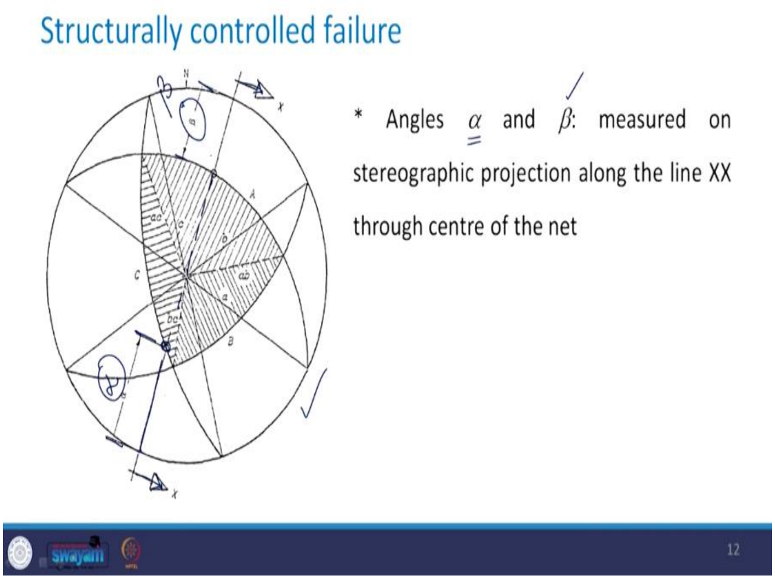

Take a look here. We have this stereographic projection. And we take this XX section here on this projection as well. And then see this α is the apparent value for this plane A and β was for C. So, this is how you see that it is obtained that from this point in the direction perpendicular to this plane XX wherever this is intersecting. So, this is how this angle α can be measured.

And this is how the angle β is measured from the stereographic projection along the line XX through the centre of the net. So, you see, this is how this XX line is passing through the centre of the net.

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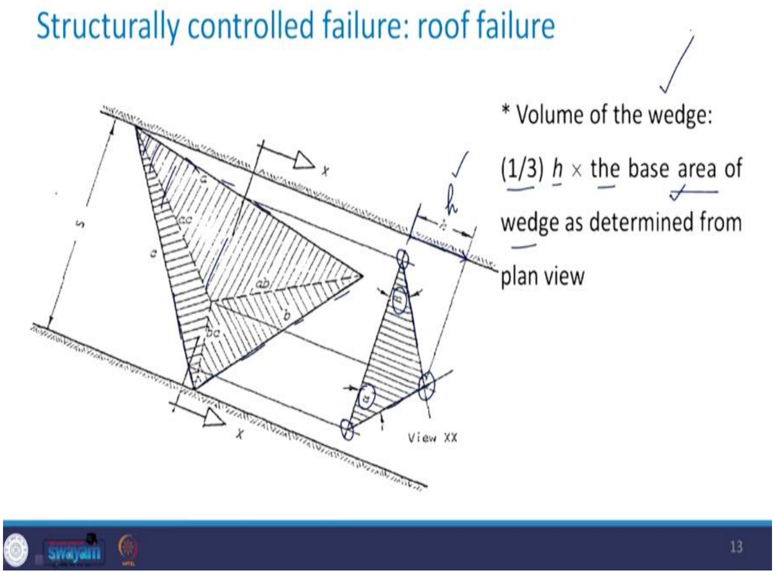

Now, how to obtain the volume of this wedge? So, that is going to be one third of the height multiplied by the base area of the wedge. Now, how to determine this base area? See, you know this sides of these triangles. So, one can find out this area. And knowing this angle α and β, and you know these 2 points also. So, wherever these 2 lines intersect each other, that point is going to give you this dimension h from this base of this triangle in this particular manner.

So, you measure this h and you can get the area of this triangular portion. And you will be able to get the volume of the wedge. So, this is how the height and the volume of the wedge which is formed in the roof can be determined using the stereographic projection.

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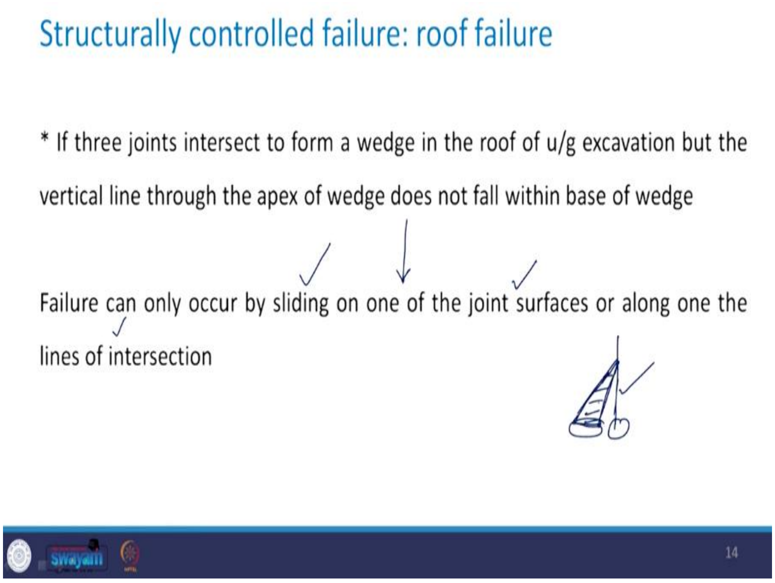

Now, if these 3 joints intersect to form a wedge in a roof of underground excavation, but the vertical line through the apex of the wedge does not fall within the base of the wedge, then what will happen? See in earlier case whatever that we discussed in that situation the vertical line through the apex of the wedge was falling within the base of the wedge. And then we said that the wedge which is being formed in the roof, it will fall in the cavity or the underground excavation.

Now, if that condition is not satisfied, that is say you can have a situation like this. That this is what is the wedge that is being formed. And this is the apex. And you see that the vertical line from the apex is not within the base. Base is here. And it is outside the base. So, what will happen in that case is that the failure can occur only by sliding on one of the joint surfaces or along one of the lines of intersection.

So, in this case falling of the wedge in the underground excavation will not be there. However, there is going to be the failure because of the sliding on one of the joint surfaces or along one of the lines of intersection of either of these 3 discontinuities.

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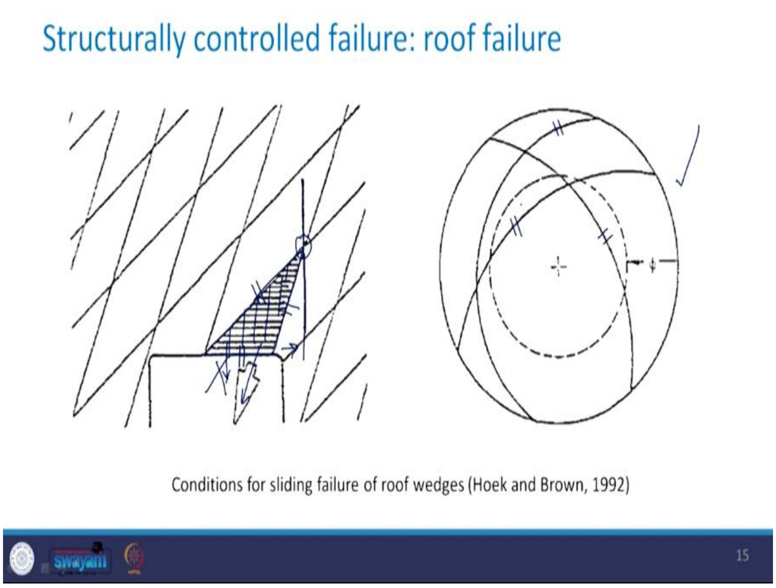

Take a look at this picture. So, this is showing you this particular condition. So, here this is what is the wedge which is being formed in the roof portion by the discontinuity. So, this shaded portion is that wedge. This is the apex. And this is the vertical line through the apex. Now, you see that it is falling outside the base of the wedge. So, it will not fall like this, but it will slide. This has been shown in the stereographic projection in this particular manner.

So, again you have 3 discontinuity planes, 1, 2 and 3, which can be represented by these 3 great circles 1, 2 and 3, depending upon what is their dip and dip direction.

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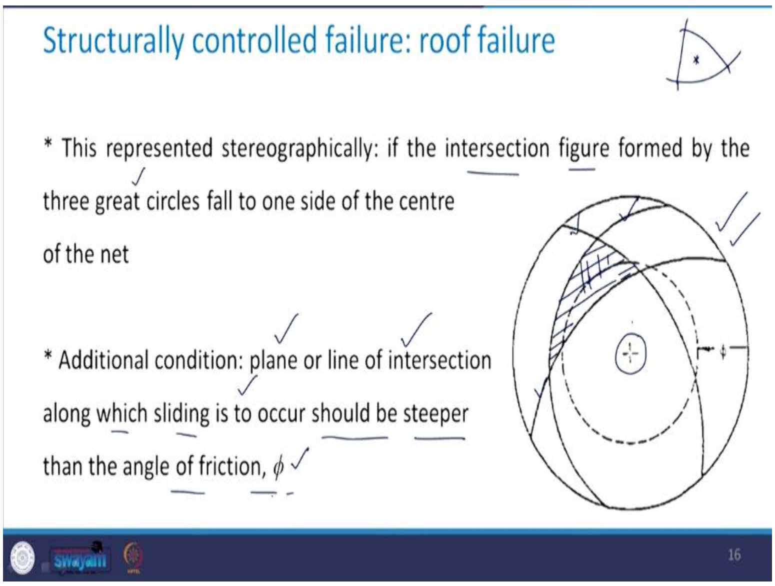

So, as I mentioned, this is stereographic projection. So, if the intersection figure which is formed by these 3 great circles fall to one side of the centre of the net. In the previous case, if you recall, this was the kind of intersection which was formed by the 3 great circles and the centre was lying inside that intersection. But in this case, you see that this these are the 3 great circle first, second and third one. And this is the intersection of these 3 great circles.

And you see the circle centre is lying here, which is not inside this intersection part. It is outside. So, that particular situation when the vertical line passing through the apex of the wedge is outside the base of the wedge can be represented stereographically in this particular manner. Now, the additional condition which is associated here is that the plane or the line of intersection along which the sliding is to be occurred.

That should be steeper than the angle of friction ϕ. Now, how to make sure or how to know whether this condition is being satisfied or not by looking at these stereographic projections see.

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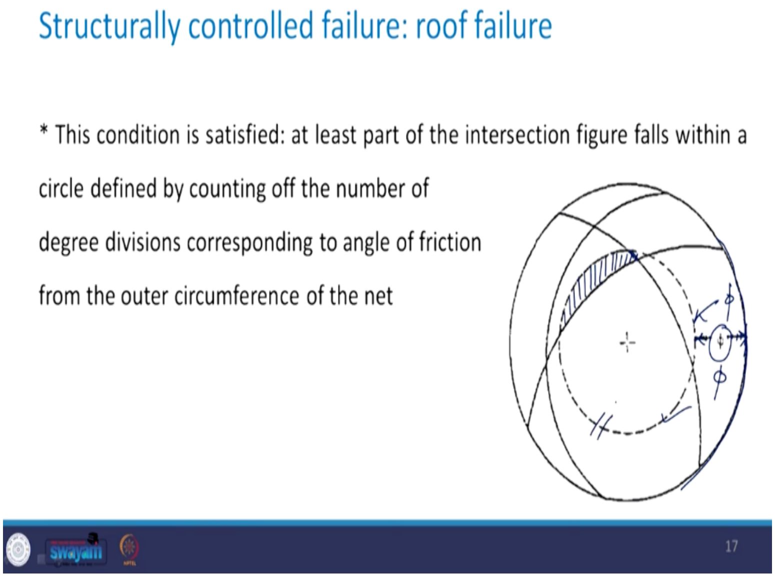

So, this condition is satisfied when at least part of the intersection figure falls within a circle, which is defined by counting of the number of° divisions corresponding to the angle of friction from the outer circumference of the net. Please try to understand, this here take a look. This is the outer circumference of the reference sphere. Now, from this we count the° divisions corresponding to whatever is the value of this ϕ.

That means measure this from this outer portion or the outer circumference. So, I can draw a circle corresponding to this value of ϕ. Now, you see that some part of this intersection is within this circle. You can see here like this, only up to this. So, this gives us the idea that the condition which we just now mentioned is being satisfied that part of the intersection figure is falling within this ϕ circle. How to obtain?

How to draw this ϕ circle is that, you count the angular division from the outer circumference. And then draw a circle corresponding to that, which has been shown here by this dotted circle.

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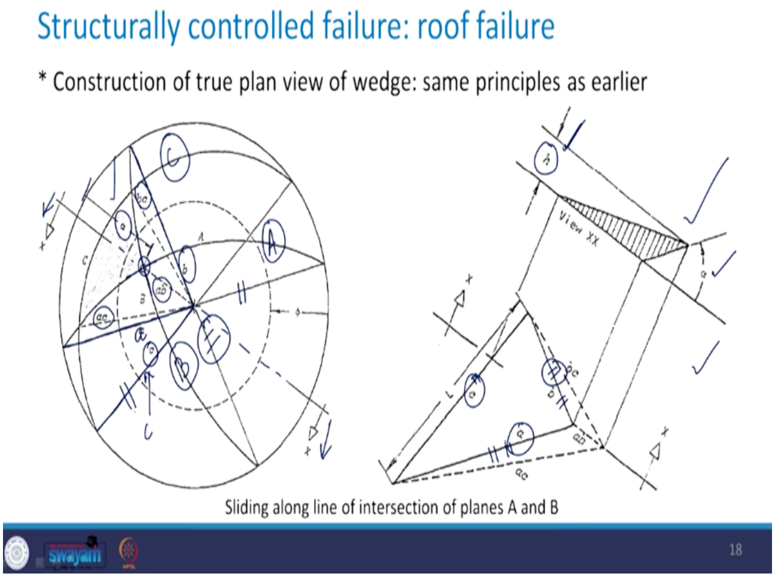

Now, the construction of the true plan view of the wedge is done following the same principles, which I already explained you in detail in the first case when the vertical line from the apex of the wedge was within the base of the wedge. So, you follow the same principle. And you will be able to obtain the construction of the true plan view of the wedge that has been shown here in this figure.

So, you see that you have the great circles, this one is great circle A. This is great circle B. And this is the third great circle, which is C. You can obtain the strike line of these like you see that this is for circle A. So, this is small *a*. This is for circle B and this is small *b*. And for the circle C, it is this line. And here it is represented as small *c*. Now, wherever they are intersecting, so, see here this is the A great circle, this is B great circle and intersecting here.

Join this with the centre and you get *ab*. Similarly, you will get *ac*. And you will get *bc*. And you can find out the angle α in such manner, which is shown here. And a Section XX which is passing through the centre of the net has been taken in this direction. So, the view is to be taken along this XX direction in this particular manner. So, exactly on those same lines, you construct this portion. Find out this height of the wedge.

You can get the angle *α* from this stereographic projection. Construct it and you will be able to get the height of this wedge. All the principles are same like the strike lines are going to be the traces here like *a*, *b* and *c*. You can see that. This line a is parallel to this one. This *b* is parallel to this line *b*. And similarly, this *c* is parallel to this line here. So, exactly those same principles need to be followed in this case as well.

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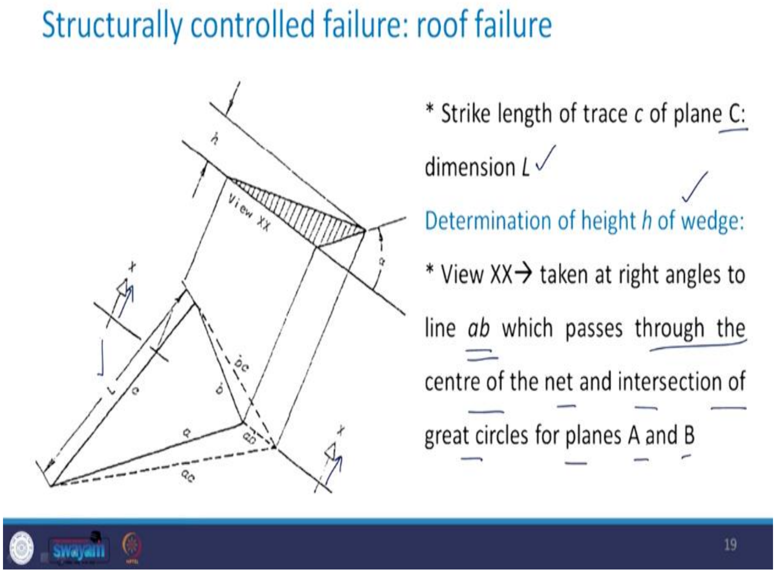

So, the strike length of trace *c* of the plane C is the dimension L which I just showed you, how will you obtain? Now, how to determine the height h of the wedge? You take the view XX. Obviously, this has to be taken at the right angles to line *ab* which passes through the centre of the net and intersection of great circles for planes A and B.

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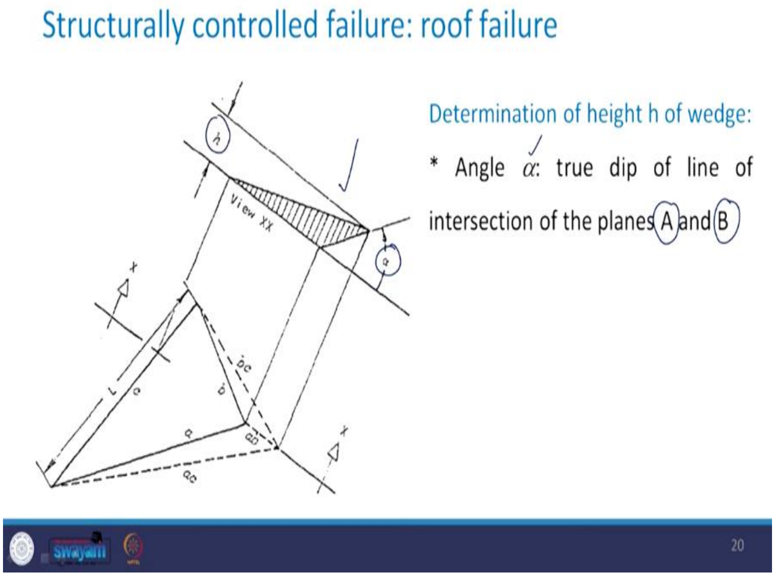

And then you can get the angle α which is the true dip of line of intersection of the planes A and B. This you have to obtain using the stereographic projection. And then plot it here in this particular manner. And this is how you have to just use your engineering graphics principles and then complete this construction in order to get the height of the wedge.

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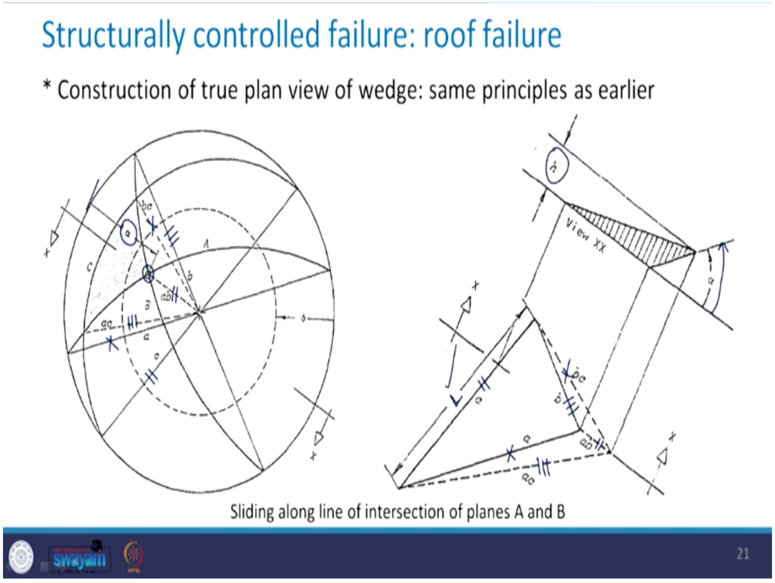

Take a look here. So, this as I mentioned already that this *c* is parallel to this line. This trace *b* is parallel to this. And a is parallel to this. This is how these are going to be constructed. This *ab* is parallel to this. *ac* parallel to this. And this *bc* here is parallel to this line. And then you know that this length, you can obtain L which is the trace. You know this angle α which is going to be see this intersection *ab* is there.

And from this outer circumference, you measure these angular division in order to get the value of α. Rotate it here in this particular fashion. And you will be able to obtain this *h*.

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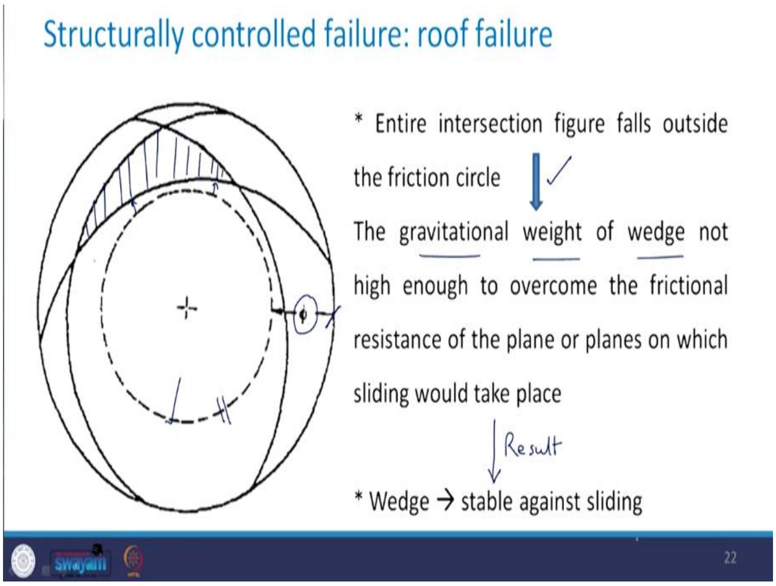

This entire intersection figure, if it falls outside the friction circle, as it has been shown here that you see that this dotted circle is giving us the ϕ circle or the friction circle. How this is drawn is you just need to take the angular division from this circumference towards the centre and then just draw this dotted circle. So, that is going to be your friction circle. In this case, you see that this is the intersection area of the 3 great circles.

And it is falling completely outside this friction circle. So, this signifies that the gravitational weight of the wedge is not high enough to overcome the frictional resistance of the plane or planes on which the sliding would take place. So, as a result, what will happen is that your wedge will be stable against the sliding. So, this is what that I wanted to discuss with you as far as the stability of the wedge in the roof portion is concerned.

That how can we find out whether it is going to fall or whether it is going to slide or whether it is stable? So, here you can see that it is one of the major applications of the stereographic projection or the graphical representation of those geological data, which we learned in one of the earlier chapters. So, this was all about the structurally controlled failure with reference to roof of the tunnel.

In the next class, we are going to take up the structurally controlled failure with reference to the wedge which is formed in the sidewalls of the tunnel. Thank you very much.