Rock Engineering

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Lecture - 42
Underground Excavation Failure Mechanisms

Hello everyone. In the previous class, we discussed about the stress distribution around a circular tunnel in the rock, which was behaving in an elasto-plastic manner and following Tresca yield criterion. We saw some of these special features. With respect to that, we saw that how we can find out the radius of elasto-plastic boundary. We further notice that in case if the yield stress is of the same order of the in-situ stresses, then the entire rock will be in the elastic state only.

And it will not behave as an elasto-plastic manner. So, today we will learn few aspects related to underground excavation failure mechanisms. Then, we will see that what do we mean by structurally controlled failure, followed by the discussion on how the stereoplots can be useful in case of the underground excavations. So, let us first start with various underground excavation failure mechanisms.

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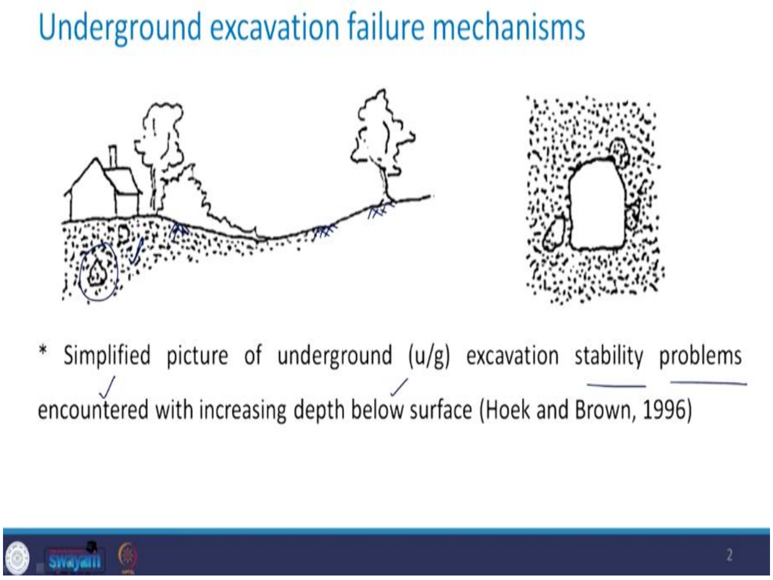

So, here is a simplified picture of an underground excavations and related stability problems which are encountered with increasing depth below the surface. So, you can see that this is the ground surface. And if we take up any kind of underground excavation, then how is going to be the influence in the surrounding rock or the soil mass? And what will happen when the depth of these underground excavation is increased below the surface?

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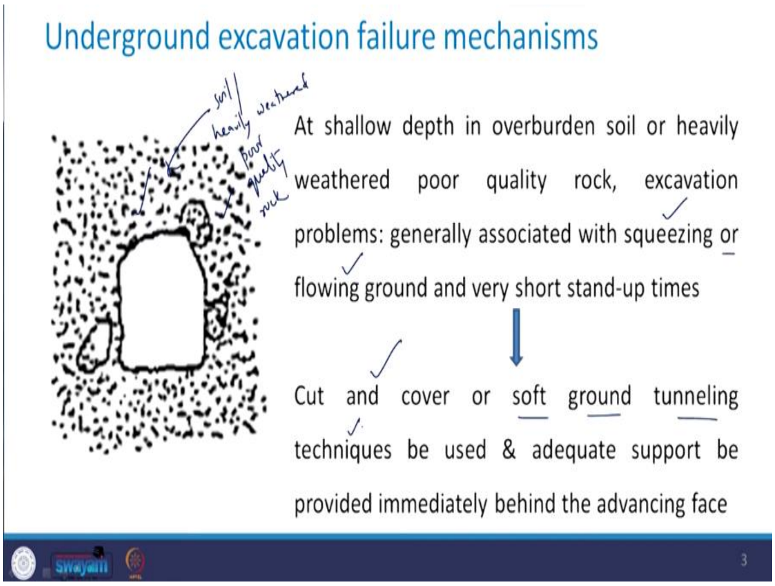

So, in case if you have the underground excavation at shallow depth in the overburden soil or heavily weathered poor-quality rock, the excavation problems are generally associated with squeezing or flowing ground and there are very short stand-up times. For example, here in this picture, you can see that this is the kind of soil or heavily weathered poor-quality rock. So, when you make the excavation in such type of rock, mainly squeezing or flowing ground will be the associated problem.

And obviously, the standard time in such cases is going to be very small. And therefore, cut and cover method or soft ground tunneling techniques should be used for the excavation purpose. And in view of very low stand-up time, adequate support should be provided immediately behind the advancing face of the tunnel.

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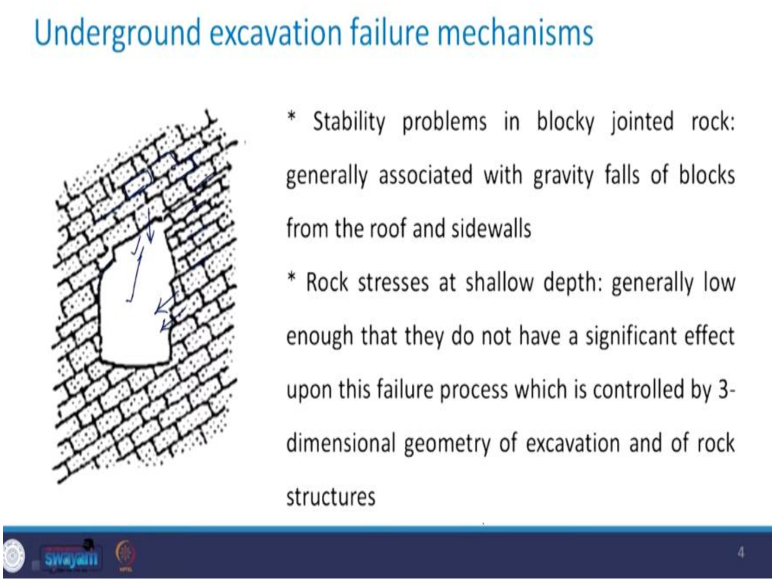

What will happen in case if you have the blocky jointed rock as has been shown in this figure? You can see that these are the blocks. And it is the joints are also there. And then you go for this kind of excavation. Now, in such type of situation the problems which are associated they are generally related to the gravity falls of block from the roof or sliding from the sidewalls.

So, you will see that in this picture, the moment I excavate, this is a stress-free boundary. And let us say this block if it gets loosened it can directly fall or maybe this block can slide. There is always the possibility of these. Rock’s stresses at shallow depths, they are generally low that they do not have the significant effect upon this failure process, which is usually controlled by 3 dimensional geometry of the excavation and of the rock structures.

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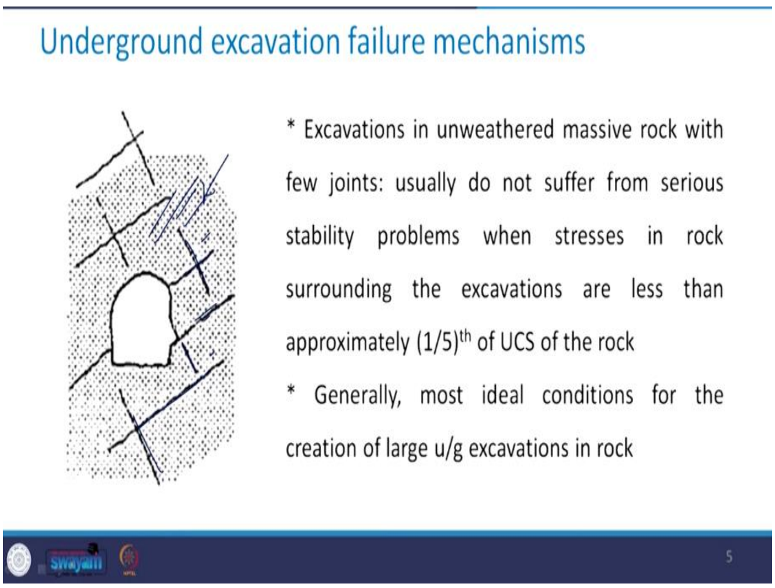

In case if you have to go for the excavation in un-weathered massive rock with few joints, as has been shown in this figure. You can see that here the rock quality is pretty good. And there are just few joint sets. Usually, such type of excavations does not suffer from serious stability problems when the stresses in rock surrounding the excavations are less than approximately one fifth of the UCS of the rock.

Generally, these are most ideal conditions for the creation of large underground excavations in rock.

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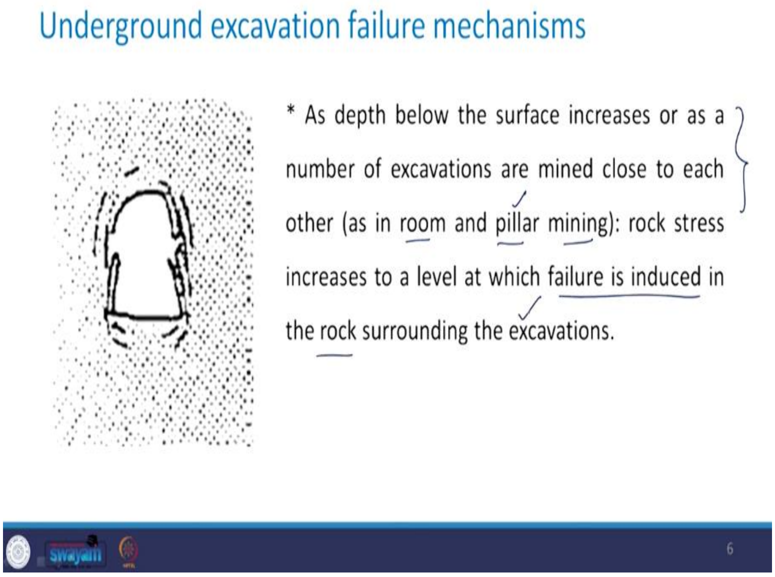

But what happens? When the depth below the surface increases or maybe in such type of rock mass, you have more number of excavations, which are close to each other, as happens in room and pillar mining. In such type of situation, rock stress increases to a level at which the failure is induced in the rock surrounding the excavations.

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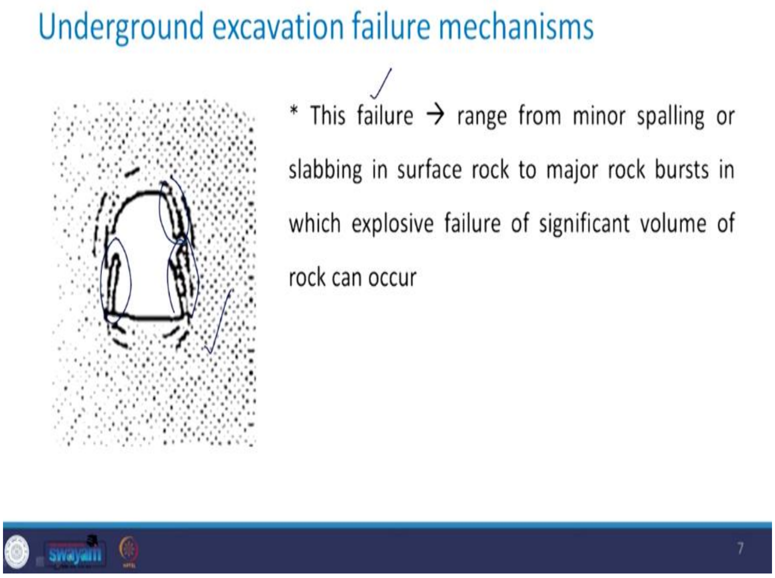

And, which type of failure? So, this failure may range from minor spalling or slabbing in surface rock to major rock burst in which explosive failure of significant volume of rock can occur. Take a look at this picture where it has been shown that how this spalling or slabbing at the surface rock is occurring in such type of situation. And I have already explained you in earlier classes that what do we mean by this rock burst is the immense amount of energy when it gets suddenly released.

Then it is kind of explosive failure. So, that also can happen in such type of rock masses when we go for the underground excavation.

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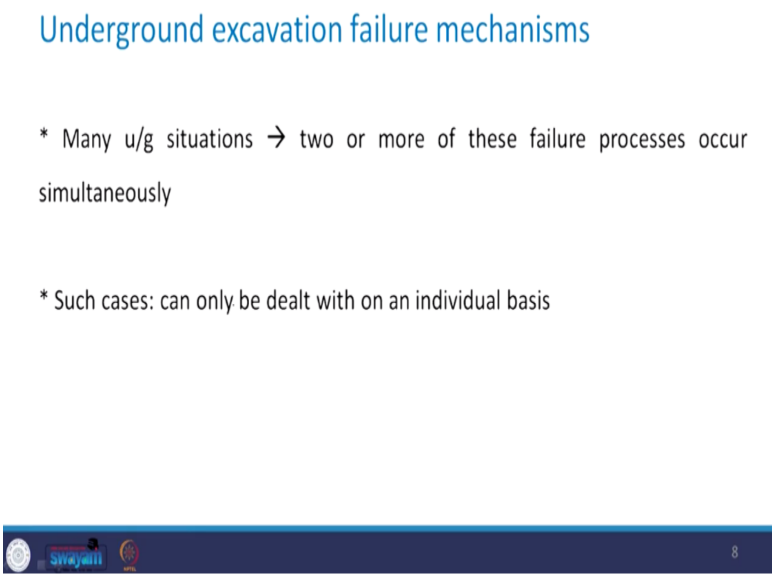

Now, in many underground situations, 2 or more of these failure processes may occur simultaneously. And obviously, the analysis in such situations they are going to be quite complex. So, all such cases should be dealt with on an individual basis. That is at one particular case, what is the situation? And the analysis should be done accordingly. Coming to the aspects related to structurally controlled failure.

In the tunnels which are excavated in jointed rock mass at relatively shallow depth, the most common types of failure which is observed is the wedges which are falling from the roof or sliding out of the sidewalls of the opening.

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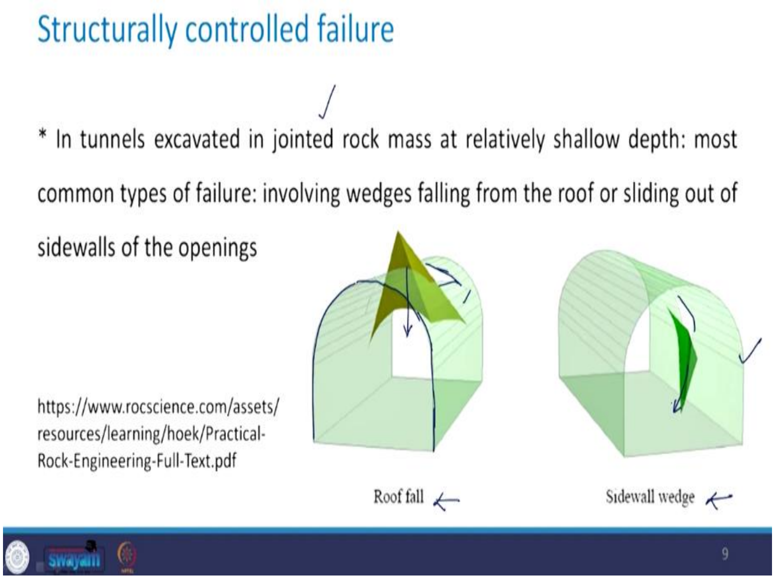

Now, take a look at these 2 pictures. The first one deals with the roof fall and the second one handles the sidewall wedge. So, you see that the excavation of this shape has been made in the rock mass, which is the jointed rock mass. And there is a wedge formation in the roof portion of the rock mass or of this excavation. And there are chances that this wedge which is formed in the roof may just fall inside the excavation.

Or, here in case of the sidewall wedge, a wedge can form here. And this can slide out of the sidewall of the opening. So, these are called as structurally controlled failure.

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Take a look at these 2 pictures, where the wedges from the roof have fallen. And you can see here that a wedge from this portion has fallen in the excavation. And in this case, you can see that the clear-cut wedge has been formed and it has fallen here. So, this is what that I meant by the roof failure.

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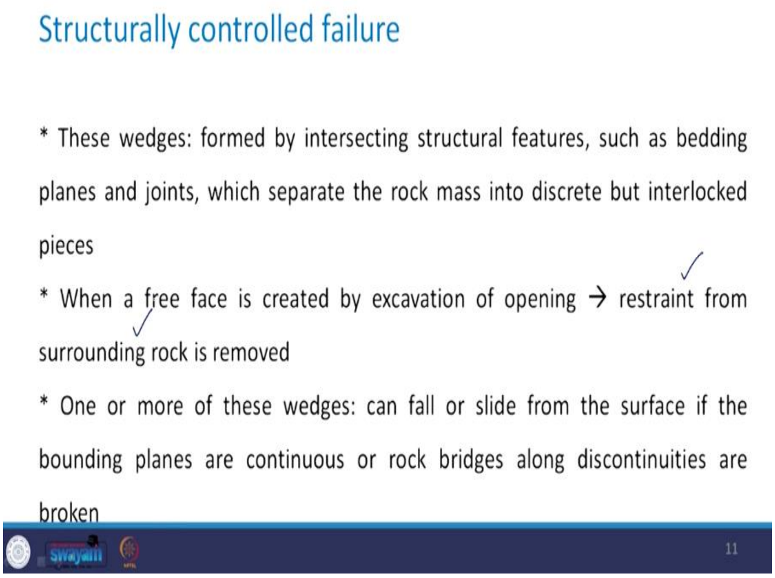

These wedges are formed by intersecting these structural features such as bedding planes and joints, which separate the rock mass into discrete but interlocked pieces. Now, when you make the excavation, because of that, a free face is created and this results in to the removal of restraint from the surrounding rock. One or more of these wedges can fall or slide from the surface if the bounding planes are continuous or rock bridges along the discontinuities are broken.

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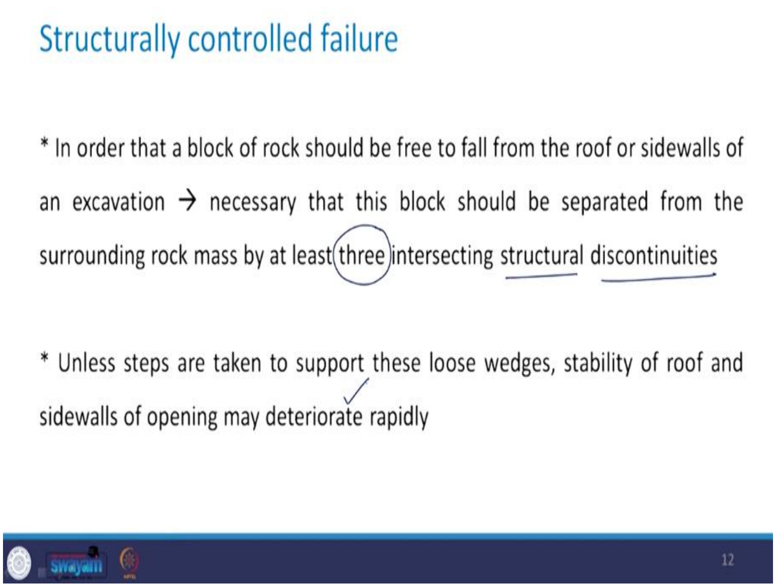

Then, in order to prevent the block of rock to fall from the roof or the sidewall of that excavation we need to provide the appropriate support system. Because this block of the rock would be free to fall from the roof or the sidewall of an excavation only when this block is separated from the surrounding rock mass by at least 3 intersecting structural discontinuities. Unless the steps are taken to support these loose wedges, stability of roof and sidewalls of the opening may deteriorate rapidly.

So, in case if there are chances of formation of such wedges in the rock mass, where the underground excavation is being carried out, then we have to take care of the support system in order to prevent these loose wedges fall either from the roof or slide from the sidewall of the opening. Each wedge which is allowed to either fall or slide, it causes a reduction in the restraint and the interlocking of the rock mass.

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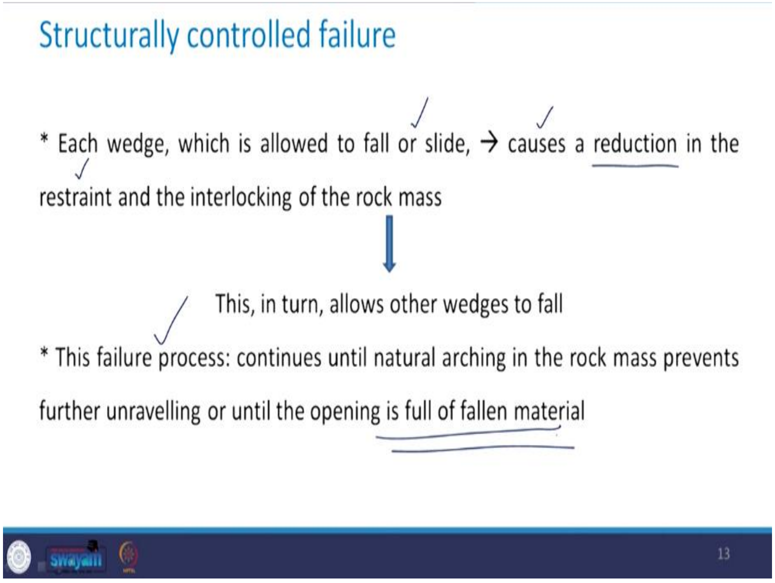

And, what happens because of this? This in turn allows other wedges to fall. And, this failure process it continues until the natural arching indie rock mass prevents further unravelling or until the opening is full of fallen material. And when the opening is full of fallen material, obviously no more material can fall into the opening and that is not desirable, because we have to proceed further with this tunneling operation. And therefore, this is the most undesired condition.

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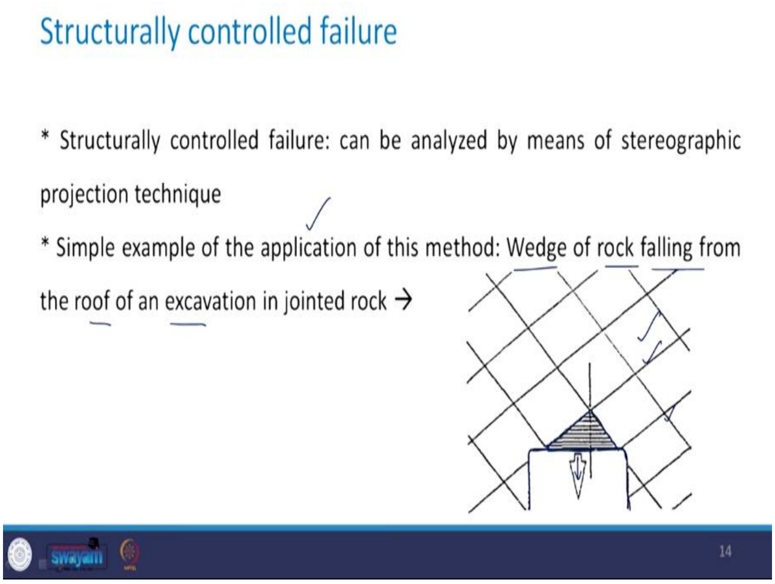

This structurally controlled failure can be analyzed by means of stereographic projection techniques. If you recall our discussion on the spherical projection of the geological data, we discussed that, how the planes, how the intersection of 2 planes can be represented with the help of stereo nets? At that time, I mentioned to you that we will be discussing about the application areas of these geological graphical representation in the subsequent classes.

So, one of the application areas is going to be the analysis of these structurally controlled failure, which we will be discussing in coming 2 or 3 classes. So, a simple example of this application is the wedge of the rock falling from the roof of an excavation in the jointed rock. Take a look at this picture. This is the jointed rock. And here is the excavation which has been made.

Now, you see that this wedge which has been formed by these 3 planes, it can fall in the cavity or the excavation. Now, how to analyze this using this stereographic projection technique?

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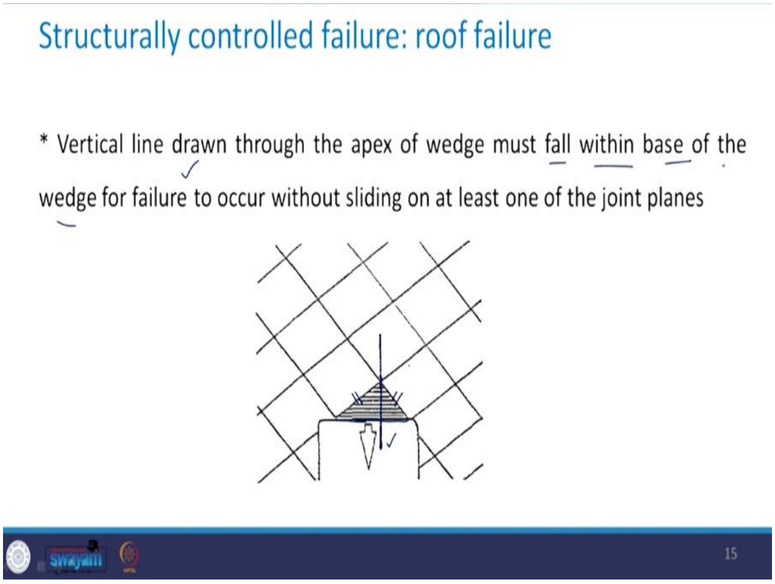

So, we draw a vertical line from the apex of this wedge. Now, this line must fall within the base of the wedge for the failure to occur without sliding on at least one of the joint planes. Now, if this vertical line does not fall within this base, what does that mean? That this wedge will not fall in the cavity or the excavation, but it will have the tendency to slide along the plane of the discontinuity which are or which may be this plane or this plane.

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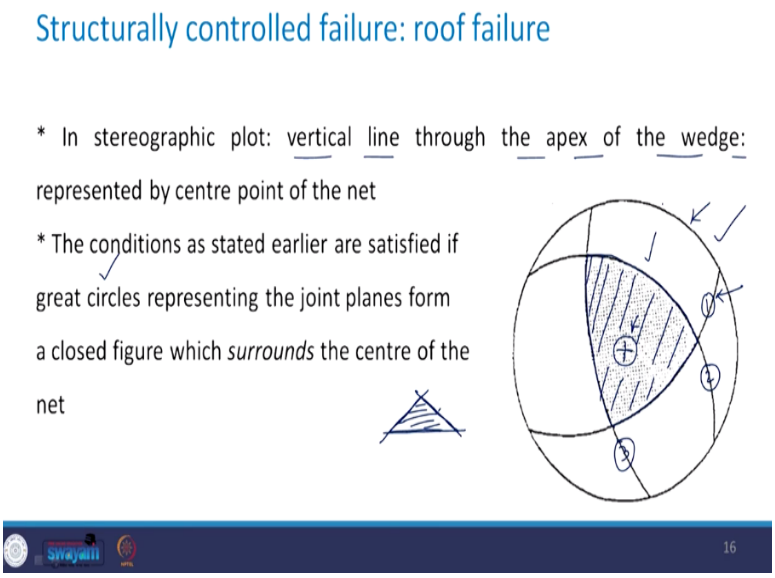

Now, how this stereographic projection technique can be helpful in order to analyze this situation? So, you can see here that in our stereographic plot, the vertical line through the apex of the wedge is represented by this centre point of the net. The conditions as we stated earlier, that is that vertical line through the apex should pass through the base of the wedge. That condition is satisfied if the great circles representing the joint planes form a closed figure which surrounds the centre of the net.

If you recall our earlier discussion with respect to the graphical representation of the plane, I mentioned to you that the plane can be represented either by the great circle or with the help of pole. So, that wedge which is formed by these planes in the previous figure. So, we have this plane, we have this plane and we have this plane as well. These are the 3 planes. We can get the dip and dip direction of these 3 planes.

And represent these in the stereo plot with the help of these great circle say this is great circle one, this second and this is the third one. And you can see that the common intersection area is this, which is the hatched portion. That is, the all these 3 great circles, they form a close figure and the centre of the net is lying inside this closed figure which is represented by this. See, it is this.

This is the closed figure. So, since it is happening in this case, so, one can say that the wedge will fall in the cavity.

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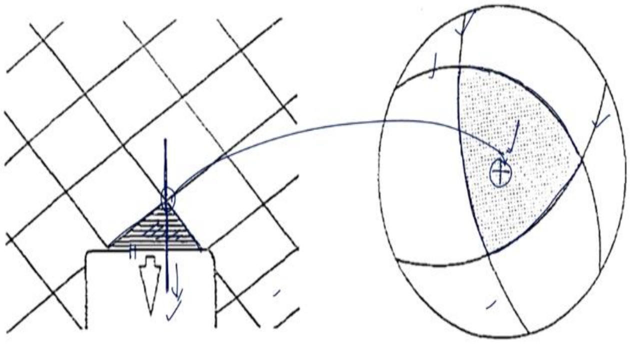
Structurally controlled failure: roof failure



Conditions for gravity falls of roof wedges (Hoek and Brown, 1996)

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Take a look again. I have put here both the figures on the same slide. This is the vertical line passing through the apex of this wedge which is this. This is being represented by the centre of this circle. These planes which are showing the discontinuity, they are being represented by great circles 1, 2 and 3. They form a close area. And this centre is lying within this closed area.

So, this means that this wedge is going to fall here as gravity. Or, this wedge is going to have the gravity fall from the roof.

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Structurally controlled failure: roof failure

* This simple kinematic check: useful for evaluating the potential for roof falls during preliminary studies of structural geology data which have been collected for the design of an underground excavation

* Stereographic method: can also be used for a much more detailed evaluation of shape and volume of potentially unstable wedges

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So, this simple kinematic check, they are useful for evaluating the potential for roof falls during preliminary studies of structural geological data, which have been collected for the design of an underground excavation. These stereographic methods can also be used for a much more detailed evaluation of shape and volume of potentially unstable wedges. How this is done? We will take this up in the next class.

So, to summarize, we learnt about the failure mechanism in different types of rock masses in case of the underground excavations. And then we learnt about the structurally controlled failure. We saw that in case if we go for the excavation in the jointed rock mass, there may be the chance of a wedge fall from roof or there may be a chance of sliding off a wedge from the sidewall of the underground excavation.

This stereographic method can be useful in order to identify these possibilities of roof fall or the side or the sliding of the wedge from the sidewall. How? In detail, we are going to learn it in the next class. Thank you very much.