Underground Space Technology
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Module No # 06
Lecture No # 27
Opening in Laminated Rocks – 04

Hello everyone, in the previous class, we discussed about the openings in a laminated rock where the roof may be inclined. So, let us continue the discussion from the previous lecture. Today we will see that those 3 cases, how we can define those, and how we can determine the maximum possible support system. Or how we can find the optimum support system for each of those cases? So, as I mentioned that we had 3 cases, and we were discussing about this case 1 and this particular aspect of case 1 we already discussed just for the continuation.

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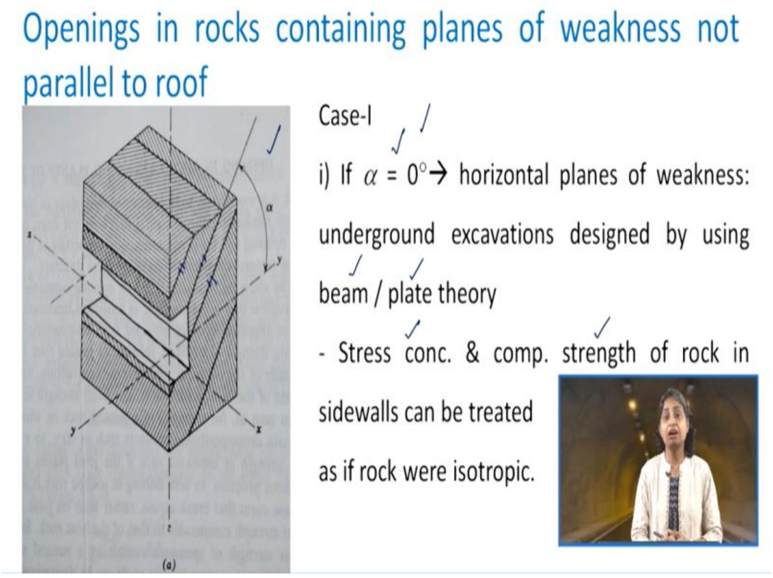

Let me repeat it once again that in case if the belts are not parallel to the roof or they are inclined as shown in this figure. And in the case 1, where the lamination or inclined in a way as shown in this figure and if this α is equal to 0 degree. This means that we are going to have the horizontal plane of weakness, and therefore the horizontal excavations are going to be designed either by beam or plate theory based upon the aspect ratio of the opening.

Second, this was that the stress concentration and compressive strength of the rock in the side walls they can be treated as if the rock were isotropic. So, this we discussed in the previous class, and I mentioned to you that there can be various ranges of α that we will consider, and based upon that we will be deciding that what will be the optimum support system.

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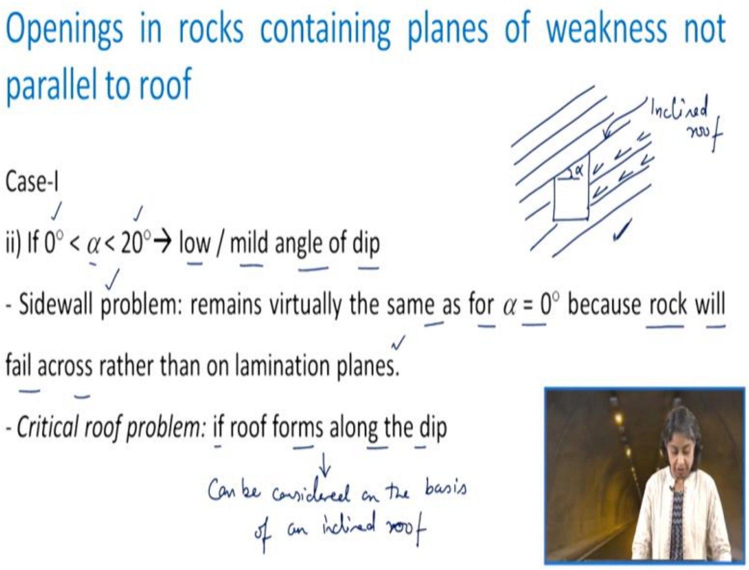

So, we take the another case where this α varies between 0 degree to 20 degrees; this signifies the low or mild angle of dip. What happens to side walls? There comes a problem that is that the side walls remain virtually the same as far α equal to 0 degree because, in this case, now rock will fail across rather than on the lamination planes. So basically, in this case, the critical roof problem is going to be when the roof forms along the dip.

So, take a look here how are we going to visualize this. So let us say that let me draw the figure, so this is what is the opening, and then we have the inclined roof. Now, this angle is α, and this is what is your inclined. So, what will happen there is going to be the development of these shears? So, if the roof forms along the dip, it can be considered on the basis of an inclined roof as has been mentioned in this particular figure.

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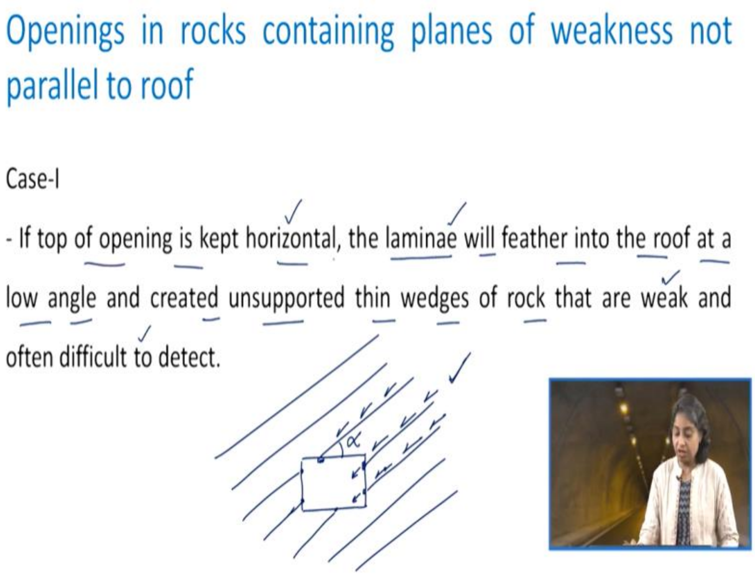

Now, if the top of the opening is kept horizontal, what will happened to the layers is lamina will feather into the roof at a low angle. Because α is between α is in between 0 to 20 degree, and there is going to be the creation of unsupported thin wedges of rock which will be weak, and it will be very difficult to detect these. Let us take a look that how this will look this so in this case, you see that you have the roof of the excavation as the horizontal one.

But then you have the inclined lamina planes. Now there is going to be the development of shear here. And see, wherever they intercept the roof of the side wall, there is going to be the formation of wedge. Here than in this region which will try to move like this in this region here also then here. And these are going to be very difficult to detect, so therefore this creates the problem.

Now, this happens here this angle is α. So, what happens is we need to be careful for deciding the inclination of the roof of the opening because if we keep it horizontal, this is what is going to be the problem.

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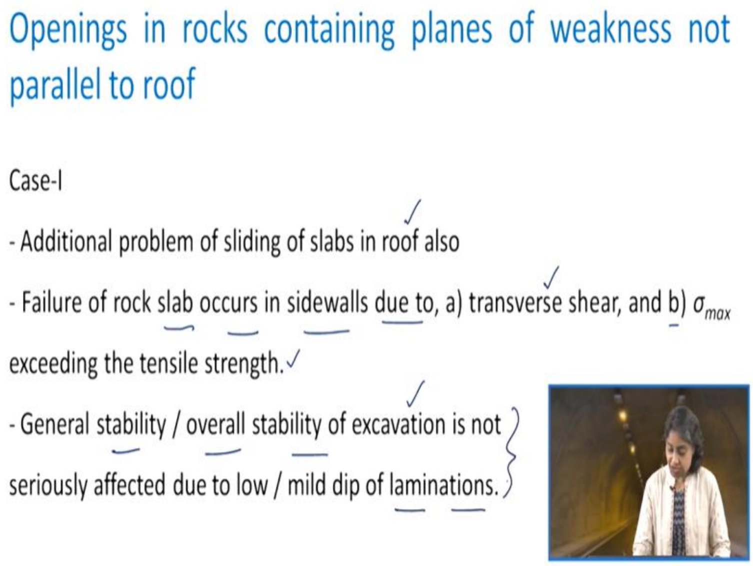

Now there can be additional problem of sliding of slabs in roof also. Failure of rocks slabs will occur inside walls because of 2 reasons one is due to the transverse here, and the other one is that the value of the maximum normal stress exceeds the tensile strength. Now, in this case, the general stability or the overall stability of the excavation will not be seriously affected due to low or mild dip of lamination, so here is the catch.

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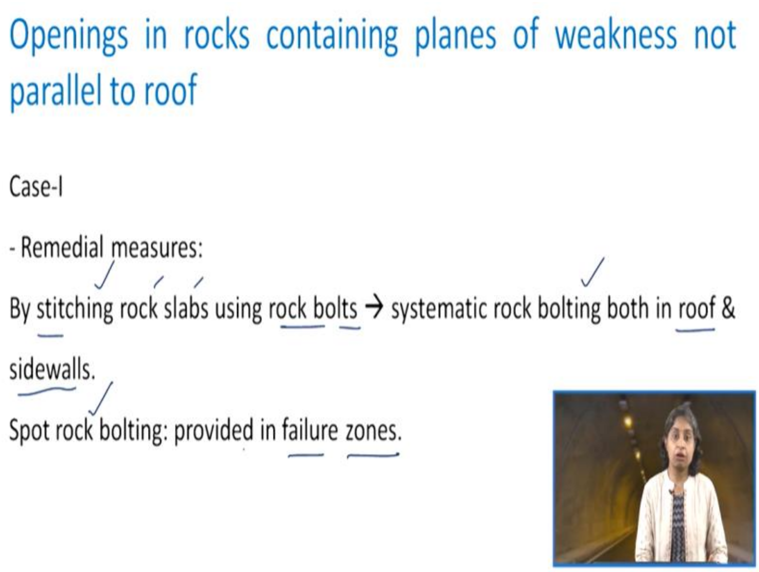

So what is the remedial measure? In case if α varies between 0 and 20 degree so what we need to do is? One needs to provide the rock bolts to stitch the rock slabs, and both in the roof and the side walls of the excavation, systematic rock bolting can be provided. Wherever you observe the failure zones, one can go for the spot rock bolting.

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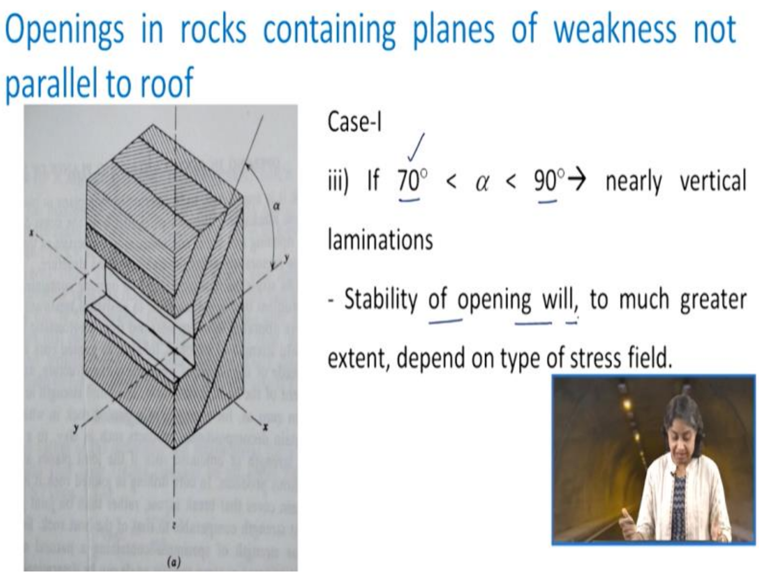

In case when α becomes even larger than 70%, that means to vary between 70 degree and 90 degree we can say that this lamination, they are almost vertical. So, in that case, the stability of the opening will depend upon the type of the stress field to much larger extent.

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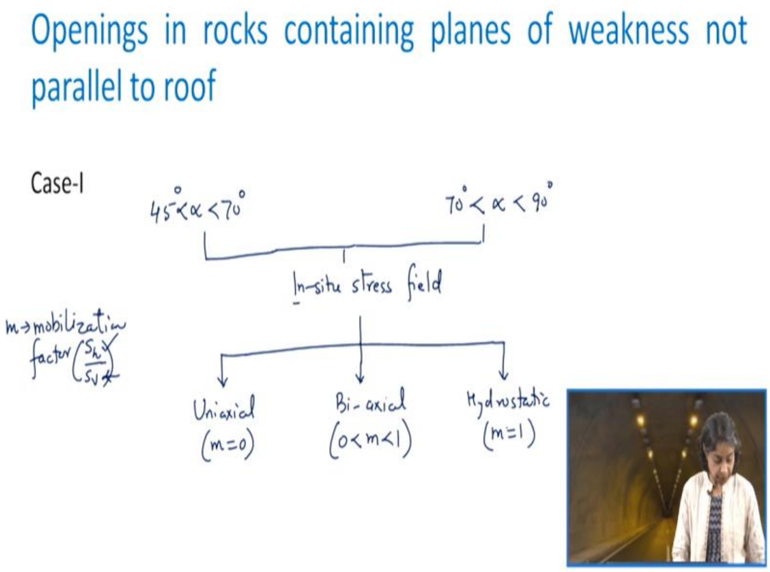

So, what all are going to be those state of stresses? So, we can have the 2 situations here, that is, when the α is varying between 45% to 70%, and another situation is going to be when it is varying between 70 to 90 degree. In both the cases, the in-situ stress field will be deciding the overall stability. Now, if you recall, we defined this in-situ stress-free situation with the factor called m, which we named as mobilization factor.

This we discussed in some of our earlier classes, and this was defined as S_h upon S_v, that means the in-situ stress in the vertical that means the in-situ stress in the horizontal direction by the in-situ stress in the vertical direction. S_h upon S_v and based upon this, we defined 3 types of this stress field one was the uniaxial state of stress, where we defined m to be equal to 0. The second one was the biaxial state of stress, where we had m varying between 0 and 1.

And if you recall, typically, we took m to be equal to 1 by 3 when we were discussing about the non-circular opening and the stress distribution. Then the third was hydrostatic state of stress there this was m was equal to 1.

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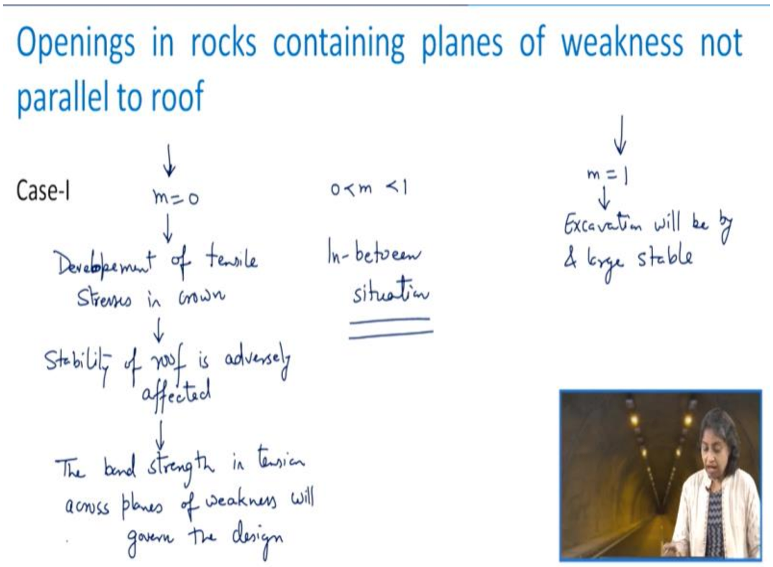

So we have different situation m to be equal to 0, then m varying between 0 and 1, and m = 1. So let us come to first the hydrostatic state of state because, in this case, the excavation will be by and large stable, the reason being that the state of stress that will be developed all around the periphery of the opening is going to be all compressive in nature. So more or less, in this case, the excavation will be by and large stable.

Coming to the uniaxial state of stress, there is going to be the development of tensile stresses in the crown portion of the opening, this we have seen earlier as well. And this will significantly affect the stability of roof. So, in this case the stability of the roof is adversely affected. So, what will happen in this case? The bond strength in tension across the planes of weakness will govern the design.

So, these are the 2 extreme situation; it is uniaxial state of stress and hydrostatic state of stress come to the biaxial state of stress, so somewhere you will have in between situation. Now, here again focus on the uniaxial state of stress that is when m = 0.

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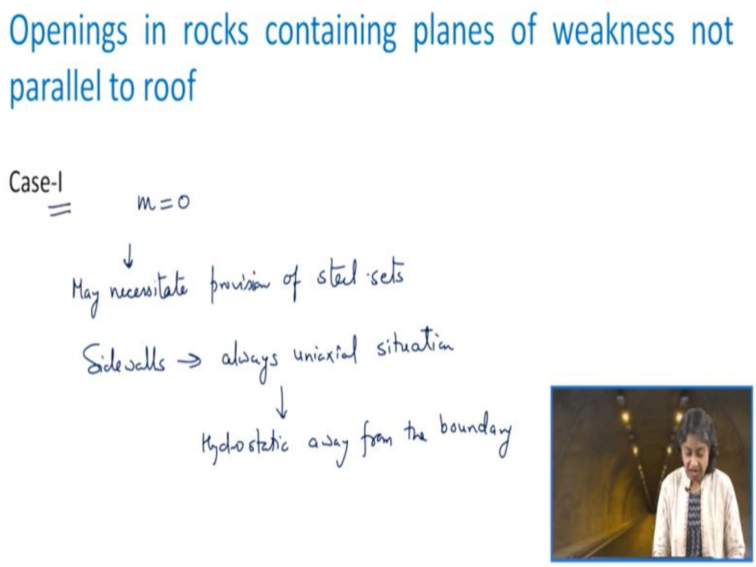

So, when we have m = 0 when this plane of weakness and the bond stress across these when they govern the design. So, then these may necessitate the provision of steel sets. Now in case of the side walls, there is always the uniaxial situation, and this is hydrostatic away from the boundary. So, therefore we need to understand all the conditions that are uniaxial, biaxial, and the hydrostatic state of stress. Always remember that uniaxial state of stress is most critical one, so this was all about case 1.

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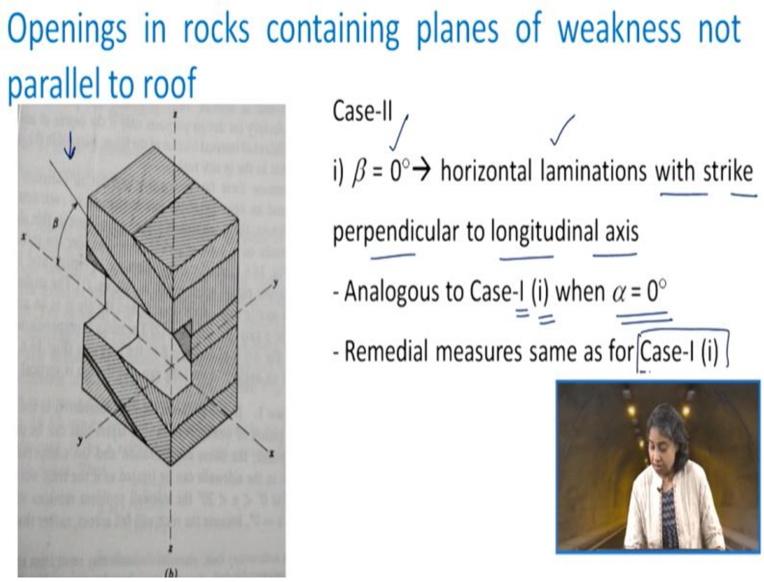

And then we had the second case where this was defined as the plane of weakness is an inclined plane as had been shown in this figure. Then the dip was defined as β degree with respect to longitudinal axis of the cavity, which is the x-x axis here, and the strike was perpendicular to the longitudinal axis as it is clear with this figure. So, in this case, also based upon the value of β, we have various situation.

So, in case if this β becomes equal to 0 so you just take a look at this figure that if this β becomes equal to 0 again, there are going to be the horizontal lamination with strike perpendicular to the longitudinal axis. And therefore, this case becomes analogous to case 1 first part, where α was equal to 0. And therefore, we can go for the remedial measures as we discussed for case one, part 1.

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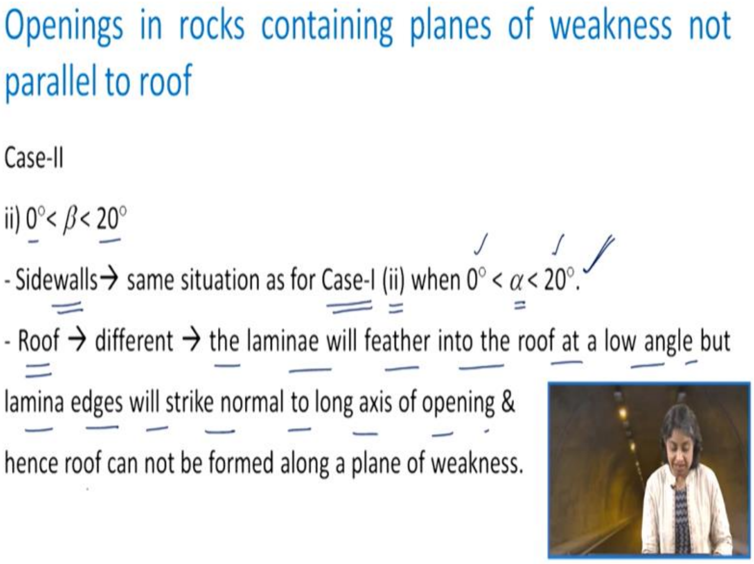

But then if β is varying between 0 and 20 degree so in this case what will happen? That the side walls will have the same situation as far the case 1 part 2 when α was varying between 0 degree and 20 degree; what will happen to roof? In case of the roof, the situation is going to be different as compared to this particular case because, in this case, the laminar will feather into the roof at the low angle.

But the lamina edges will strike normal to the long axis of the opening, and therefore roof cannot be formed along a plane of weakness. In the previous case, we could do that, but in this case, it may not be possible.

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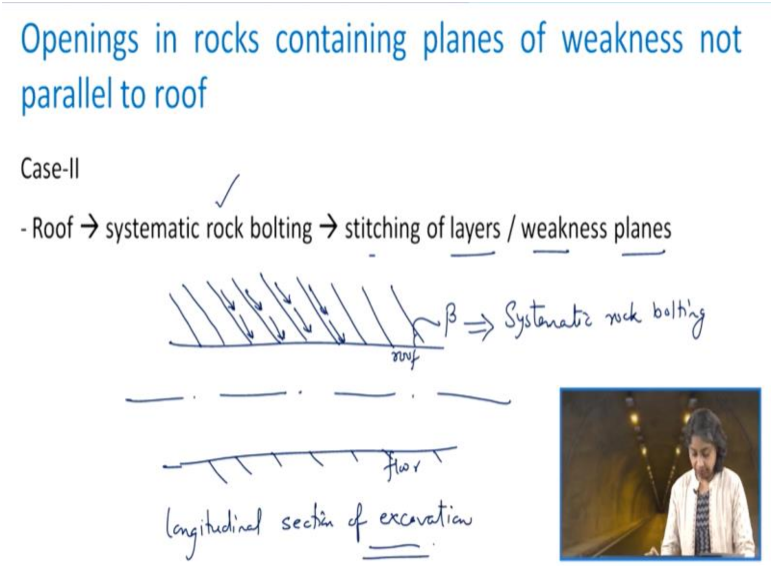

So, in the case, one has to go for the systematic rock bolting as far as the roof is concerned these results into the stitching of layer or the weakness planes. So, let us take a look that how this situation will look like? So, if you take the longitudinal section of an excavation, it will look like this that is the center line, and here is the roof portion, and this will be the floor portion. So, I will just mark this as maybe roof, and here it is the floor.

And the plane of lamination they will feather into like this angle is angle β, and there is going to be the movement like this in the roof portion. So, therefore in the roof portion, one has to be go for systematic rock bolting, so this is what here all these planes are there in the roof portion. So, what we have here is the longitudinal section of excavation.

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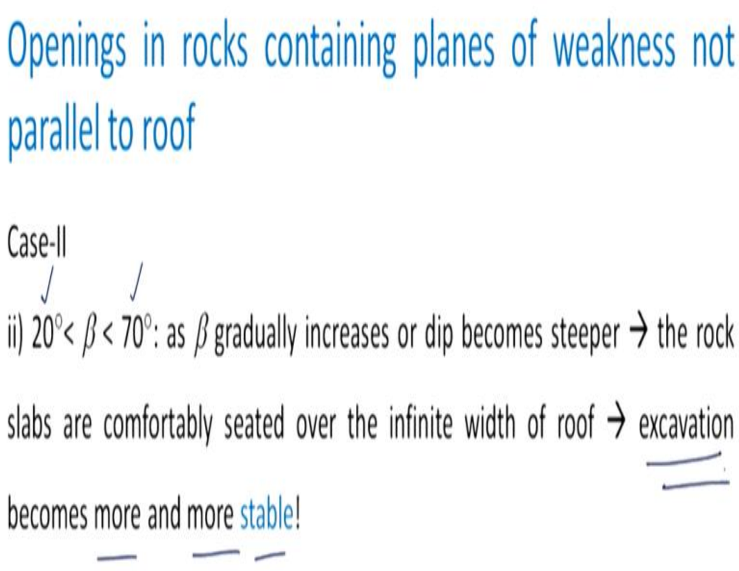

In case if this β various between 20 degree to 70 degree so, what happens is? As this β gradually increase dip becomes steeper, the rock slabs are comfortably seated over the infinite width of the roof, and this results into more and more stable excavation, so no problem for us.

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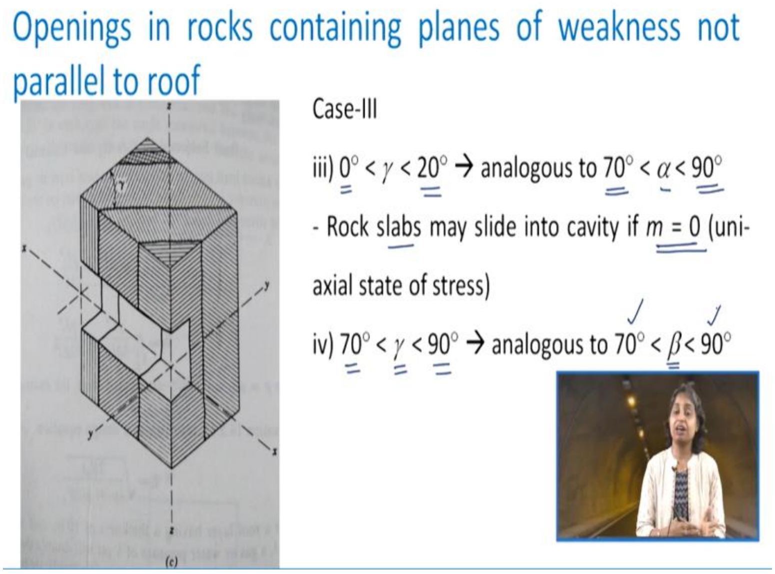

In case of the third situation, where we have the situation as shown here that is when the lamination plane when they are nearly vertical. So, in that case, again we have different situation that is when γ is equal to 0 degree. This is analogous to case 1, when α becomes equal to 90 degree, and in this case, steel sets are provided as the support system. But if γ becomes equal to 90 degree see what is this angle γ. As shown here in this figure, this angle is angle γ.

When this is 90 degree this becomes analogous to case when we have β as 90 degree, and therefore this is going to stable and most favourable condition as far as the openings are concerned. If the angle γ varies between 0 degree and 20 degree this case is analogous to the situation when you had the case 1 where α was varying between 70 degree and 90 degree.

In this case, the rock slabs may slide into the cavity for the uniaxial state of stress, that is when m = 0. And accordingly, there you have to provide appropriate and the corresponding support system. In case if you have γ angle varying between 70 degree and 90 degree this is analogous to the case when β is varying between 70 to 90 degree, and then you can refer back to the case 2 and provide the appropriate support as we already discussed.

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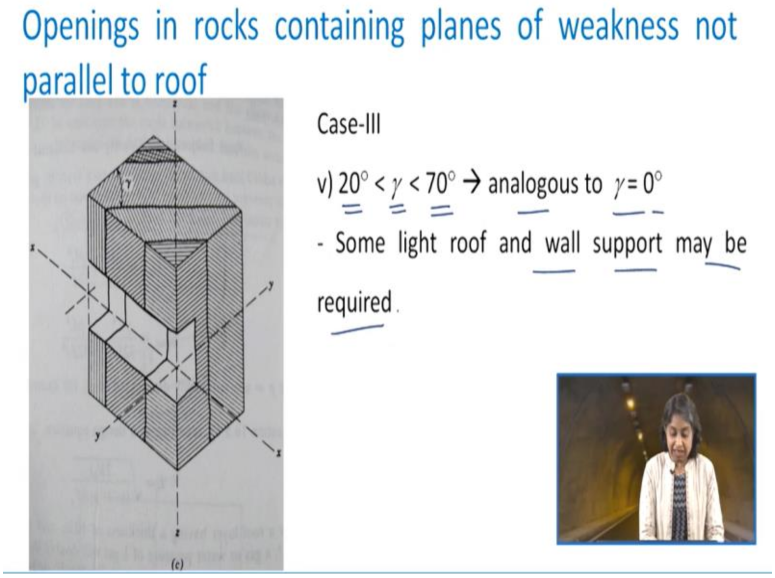

In case when γ is varying between 20 degree and 70 degree what will happen in that case this is analogous to γ equal to 0 degree. So, in this case, some light roof and wall support may be needed. So basically, from all these 3 cases, based upon the orientation of the planes of lamination with reference to the orientation of the opening. You can decide that which case it is in case if the laminar planes they are horizontal. We can use the beam or the plate theory depending upon the aspect ratio of the opening.

But in case if that is not the situation in different cases, then appropriately you can refer to these different situations and pick the appropriate support system. Thank you very much, and in the next class, we are going to discuss about the new topic, which is the elastoplastic analysis of the tunnels if you have noticed as of now, we discussed everything considering the rock as the elastic medium. But that may not be the case upon the excavation.

What happens is the surrounding rock becomes loosened, and it may enter into the plastic state. So how we go for the analysis of the opening in elastoplastic rocks that we will learn in the next class.