Underground Space Technology

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Module No# 10
Lecture No # 47

Rock-Support Interaction Analysis: Available Support for Ungrouted Rock Bolts Grouted Rock Bolts/Cables; the Reaction of the Combined Support System

Hello everyone, in the previous class we had a discussion on the determination of the maximum support pressure and stiffness for the support systems, such as shotcrete and blocked steel sets. This was in connection with the rock mass tunnel support interaction analysis. I mentioned to you, that there are many other types of the support systems, such as ungrounded rock bolts, grouted rock bolts, or cables, or sometimes, you have to provide 2 types of support in combination.

So, today we will learn about the similar analysis for the ungrounded rock bolts, grouted rock bolts, or cables and then, we will take up some cases, where we will have the combined system. Then we will see that, how the stiffness and the maximum support pressure can be obtained for such type of support systems. So, the available support for the ungrounded bolts, we will take this first.

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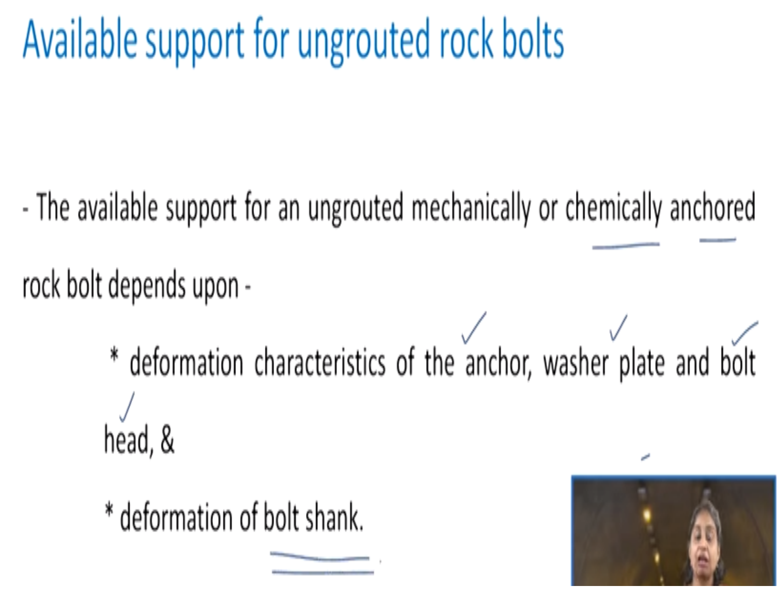

The available support for an ungrouted rock bolt, which is mechanically or chemically- anchored in the rock mass. It depends upon the deformation characteristic of the anchor washer plate and bolt head and the deformation of the bolt shank. So, before we understand about these deformation characteristics of various components of the ungrounded rock bolt. Let us first try to understand, the various components of such types of rock bolts.

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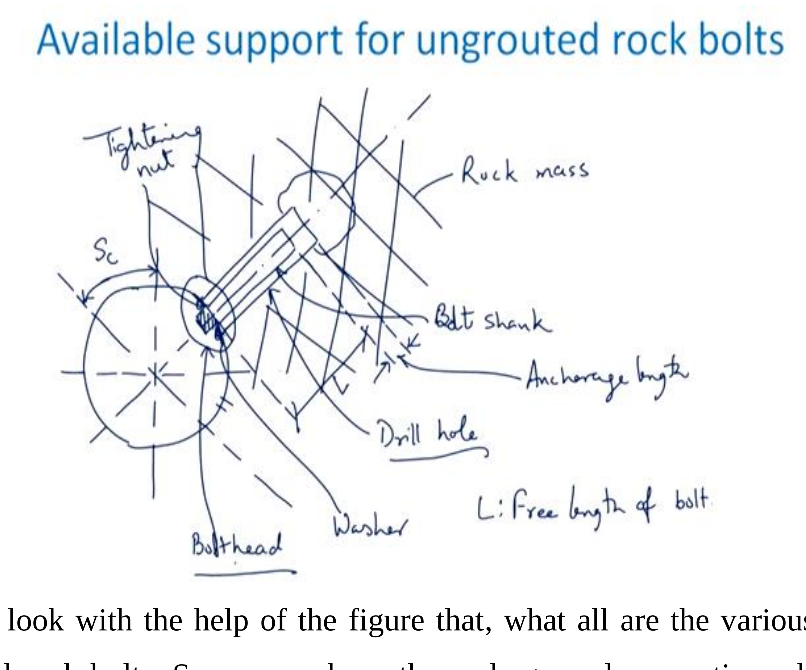

So, let us take a look with the help of the figure that, what all are the various components for these ungrounded rock bolts. So, say we have the underground excavation which is circular in cross-section. And say, that we want to go for the provision of the rock bolts in this direction like this. So, let me try to draw a typical bolt and the other components. So, here at the top, we have the bolt head tightened by the nut here and of course, here you have the rock mass.

So, in the end, this is anchored, so, this is what is your rock mass then this is what is the drill hole in which the bolt is installed so here, this is a bolt shank. Then, the complete disassembly is the bolt head this is a washer and of course, these are tightening nuts. The circumferential spacing, that is this one is S_c Coming to the length, here we have, say this is your total L and from here to here, this is what we call anchorage length.

So, these are the various components of an ungrouted rock bolt, which is mechanically or chemically anchored in the rock mass. So, what we do is, first we have a drill hole then the bolt shank goes inside that which is tightened at the surface of the excavated periphery or the opening with the help of bolt head, this is comprising of the tightening nut washer and other related stuff. So, this L we call the free length of the bolt. So now, we come to the deformation characteristic.

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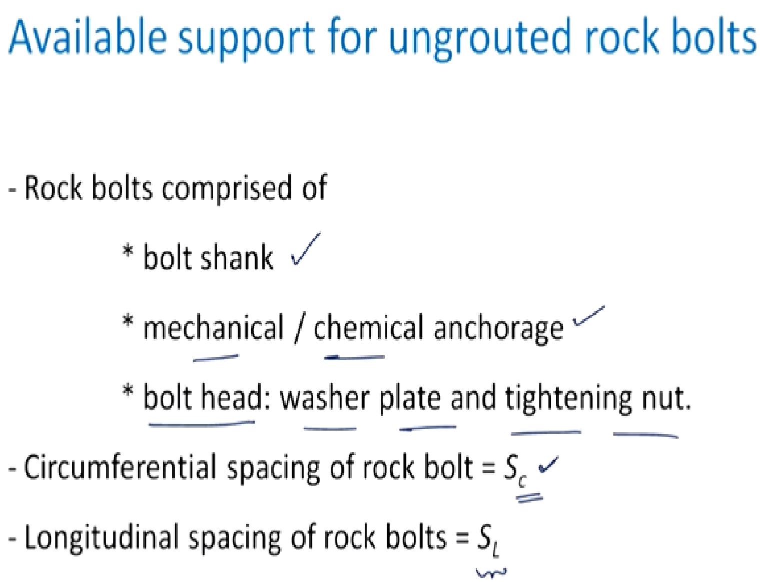

So, as we saw that, the rock bolts are comprised of bold chunks of mechanical or chemical anchorage, and then we had a bolt head, which is comprised of a washer plate and the tightening nut. Then few things which we will need are the circumferential spacing of the rock bolt which is S_C. I showed you in the previous slide, that what it will be. Then longitudinal spacing of the rock bolts is represented by S_L, which means the spacing of the rock bolt in the plane perpendicular to the plane of the screen.

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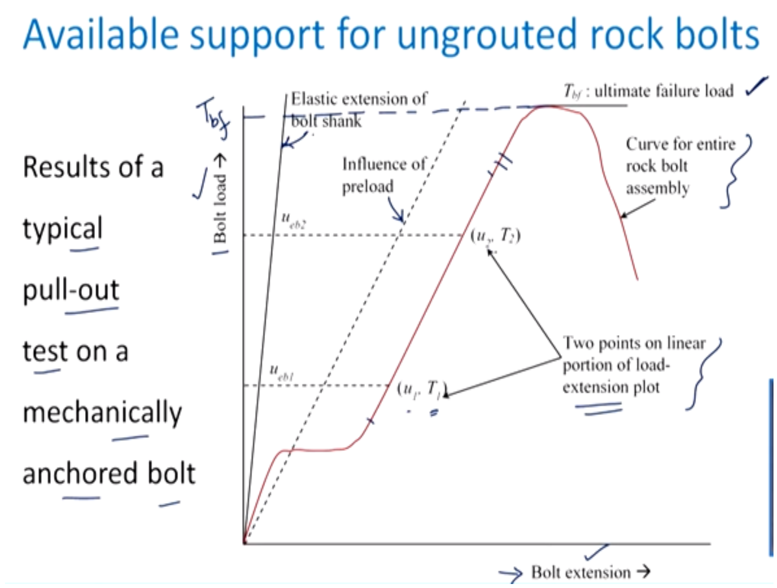

Now, the question is how to determine the capacity of the bolt. So, for this purpose, the typical pull-out load test results are shown for a mechanically anchored bolt. So, you see that the curve with the red color is the curve for the entire rock bolt assembly. So, here we plot on the X-axis the bolt extension and on the Y-axis, it is the load in the bolt or we call it to bolt load.

So, we have 2 aspects. So, the first one is the elastic extension of the bolt shank and, this is what is the influence of preload this is the complete rock bolt assembly and the response that is robot load versus the bolt extension. Now here, we take 2 points on the linear portion of the load extension plot. So, basically, this is what is the linear portion maybe to some extent so, we choose these 2 points which are represented by (u_1, T_1).

Where, this u1 is the bolt extension, corresponding to the volt load of T_1 and when the bolt load is T_2, then the extension is u_2. So, as far as the bolt shank is concerned the respective extension is u_{eb1} and u_{eb2}. Then we have the maximum value of this bolt load, which is nothing but T_{bf} that I have shown here which is the ultimate failure. So, this is what the results of a typical pull-out test on a mechanically anchored rock bolt look like. So, once we have this can we find out the stiffness of the ungrounded rock bolts. Yes, we can and then what is the procedure for that?

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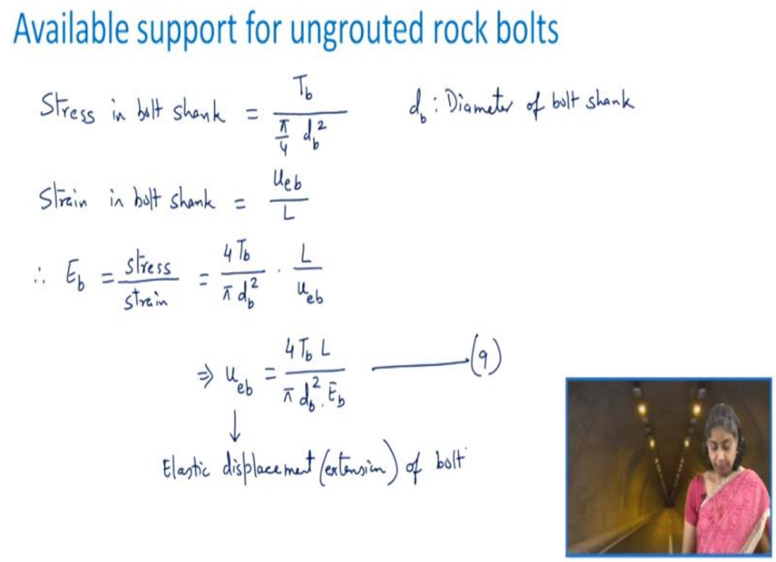

Let us take a look. So, we have the stress in the bolt shank, which is equal to

$$\text{Stress in bolt shank} = \frac{T_b}{\frac{\pi}{4} d_b^2}$$

where this db is the diameter of the bolt shank. Then the strain in the bolt shank is given as

$$\text{Strain in bolt shank} = \frac{u_{eb}}{L}$$

I already told you it is the free length of the bolt and, therefore, we will have the modulus which I am representing by

$$E_b = \frac{\text{stress}}{\text{strain}} = \frac{4T_b}{\pi d_b^2} . \frac{L}{u_{eb}}$$

So, from here we can get

$$u_{eb} = \frac{4T_b L}{\pi d_b^2 . E_b}$$

This equation is equation number 9. This is in continuation with the previous class equation numbers. So, this ueb is the elastic displacement or the elastic extension of the bolt.

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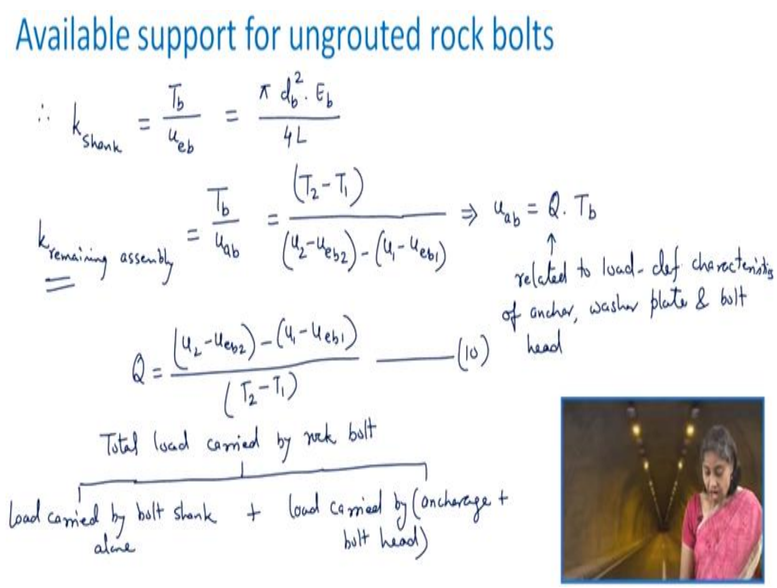

So, can we find out the stiffness yes

$$k_{shank} = \frac{T_b}{u_{eb}} = \frac{\pi d_b^2 . E_b}{4L}$$

Now, when we talk about the complete assembly see till now, we found out k of the shank that is bolt shank. But then, I mentioned to you that not only shank, but you have the bolt head assembly which is the washer plate and tightening nuts. So, how can we find out k of the remaining assembly? So, k of the remaining assembly. This is going to be

$$k_{remaining\ assembly} = \frac{T_b}{u_{ab}} = \frac{(T_2 - T_1)}{(u_2 - u_{eb2}) - (u_1 - u_{eb1})}$$

We took 2 points in the straight-line portion and that we are using so, we can say here. that

$$u_{ab} = Q . T_b$$

This Q is related to load deformation characteristics of anchor, washer plate, and the bolt head, and how we define this

$$Q = \frac{(u_2 - u_{eb2}) - (u_1 - u_{eb1})}{(T_2 - T_1)}$$

Let me make this equation number 10. So, this is how we can find out the K of the remaining assembly. Now, what will be the total load carried by the rock bolt?

So, that, we will have as the total load carried by rock bolt it will have 2 components. The first one is the load carried by bolt shank alone plus. We have another component that is load carried by anchorage plus the bolt head.

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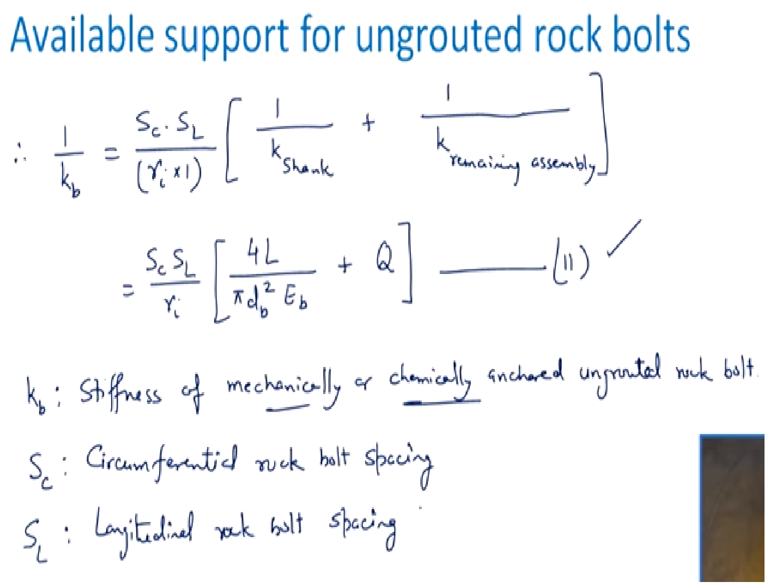

So, how should we get the total stiffness that will be said it is k_b. So,

$$\frac{1}{k_b} = \frac{s_c . s_L}{(r_i x1)} [\frac{1}{k_{shank}} + \frac{1}{k_{remaining\ assembly}}]$$

So, if we just substitute this is going to be

$$= \frac{s_c . s_L}{r_i} [\frac{4L}{\pi d_b^2 . E_b} + Q]$$

The expression of Q was given as equation number 10. So, I will mark this as equation number 11. So, where your k_b is the stiffness of mechanically or chemically anchored ungrouted rock bolt. Then S_c as I mentioned; already circumferential rock bolt spacing and S_L is the longitudinal rock bolt spacing. So, this is how the stiffness of the ungrounded rock bolts can be determined which are mechanically or chemically anchored.

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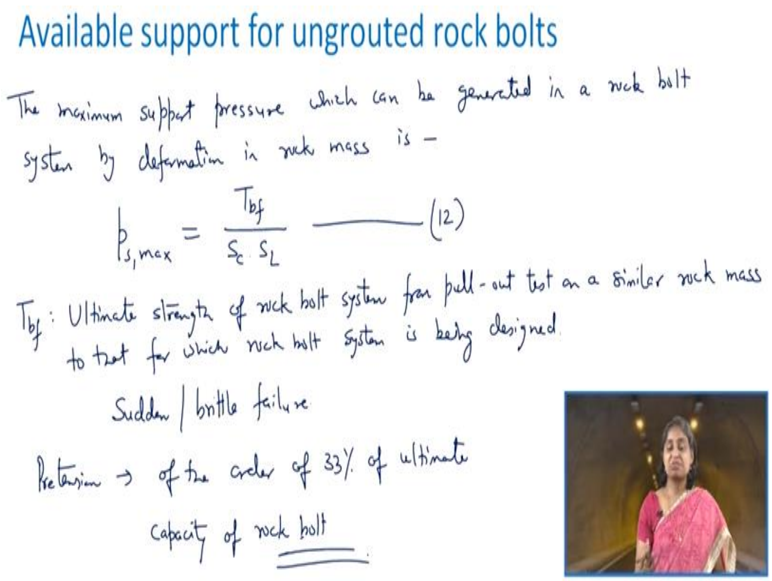
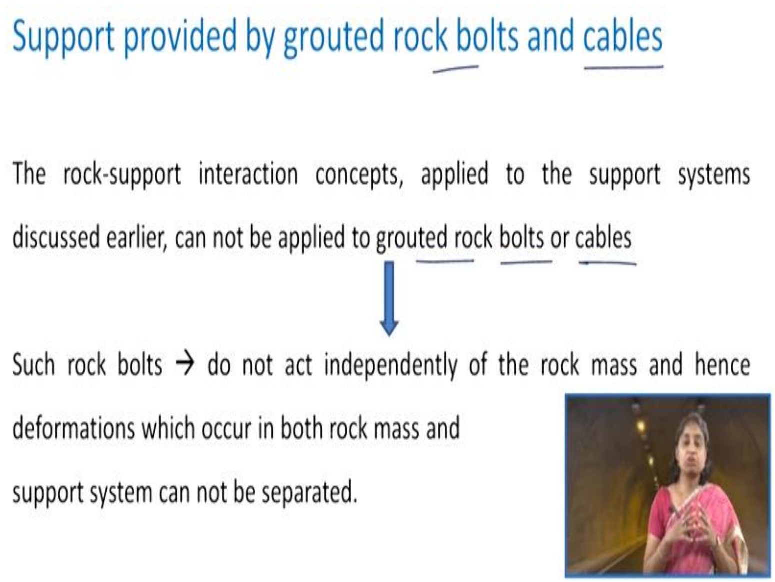


Now, what is going to be the maximum support pressure? Because, for every support system, we need 2 things one is its stiffness and another is the maximum support pressure that is available. So, in this case, the maximum support pressure which can be generated in a rock bolt system by deformation in the rock mass. That is given as

$$p_{s,max} = \frac{T_{bf}}{S_c S_L}$$

recall what was T_{bf} that was the failure load or the ultimate load.

So, I will mark this equation as equation number 12. So, this T_{bf} here is the ultimate strength of the rock bolt system from the pull-out test on a similar rock mass to that for which the rock bolt system is being designed. Now, this gives rise to sudden failure or brittle failure. So basically, we need to go for pre-tensioning. So, this is pre-tensioning which is of the order of about 33% of the ultimate capacity of the rock bolt. So, this is how we can determine the properties with reference to the ungrounded rock bolts in terms of their stiffness and the maximum support pressure. **(Refer Slide Time: 21:07)**



Now, we take the next one which is the support that is being provided by grouted rock poles and the cables. So, when we discussed this rock support interaction concept these are applied to the support system, which we discussed till now. That is shotcrete, steel sets, and ungrounded rock bolts. But then these cannot be applied to the grouted rock bolts or cables why? Because such rock balls do not act independently of the rock mass and therefore the deformation which occurs both in the rock mass and the support system these cannot be separated.

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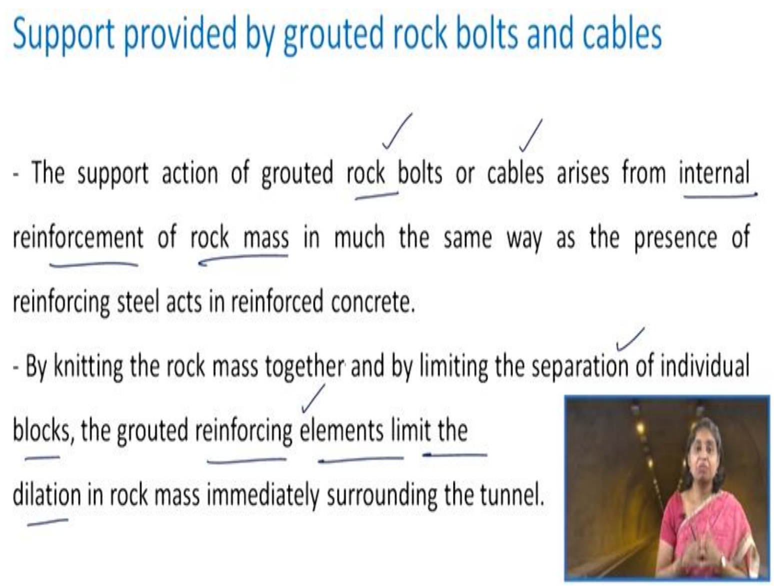

So, the support action of the grouted rock bolts or the cables arises from the internal reinforcement of the rock mass, in much the same way as the presence of reinforcing steel acts in the reinforced concrete. If you just see that, when we go for the reinforced concrete so, basically along with the steel and the concrete they behave as one unit. So, their individual behavior cannot be separated.

So, a similar type of action happens or takes place here in the case of the grouted rock bolts or cables where there is the internal reinforcement of the rock mass. So, what happens basically when you provide such a type of system that is grouted rock bolts and cables? So, basically, they knit the rock mask together by limiting the separation of individual blocks. The grouted reinforcing elements these limit the dilation or the volume increase in the rock mass, immediately surrounding the tunnel.

See, what happens? When you have the excavation, immediately in the vicinity of that whatever the rock mass it has a tendency to increase in volume. So, immediately if you provide these grouted reinforcing elements, this dilation tendency is limited in the rock mass immediately surrounding the tunnel.

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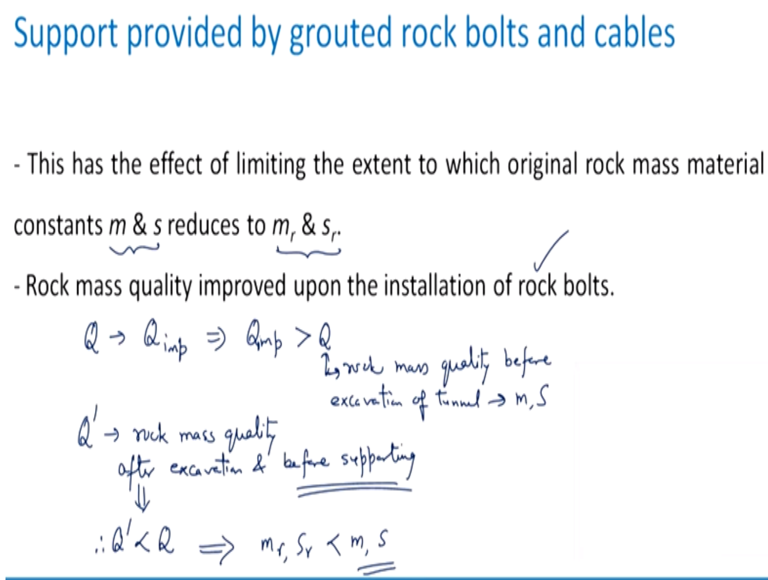

Now, this, in turn, has the effect of limiting the extent to which the original rock mass material constant which was given by m and s. They reduce to the broken rock mass parameters which are m_r and s_r. If you recall these m and s or m_r and s_r, these are the parameters of the hook and Brown criterion. So, what happens when you provide the rock bolts or when you install the rock bolts, the rock mass quality overall improves upon the installation of the rock bolts.

Now, what happens because of this? Let us take a look. So, you have this Q, which got changed to maybe Q improved. Where this Q improved will be greater than Q this Q is the rock mass quality, before the excavation of the tunnel. So, this is characterized by these parameters m and s. Now, if you have another parameter Q prime which represents the rock mass quality after excavation but, before supporting.

That means, before the installation of the support system. So, in this case, what will happen? This will be less than Q of course because the excavation has been made. So, there is going to be a deterioration in the rock mass quality since the support has not been provided. So, what we will get is Q prime is less than Q and therefore we can say that m_r and s_r, will be less than m into s. So, basically this m r and s r will be less than m and s which was for the original rock.

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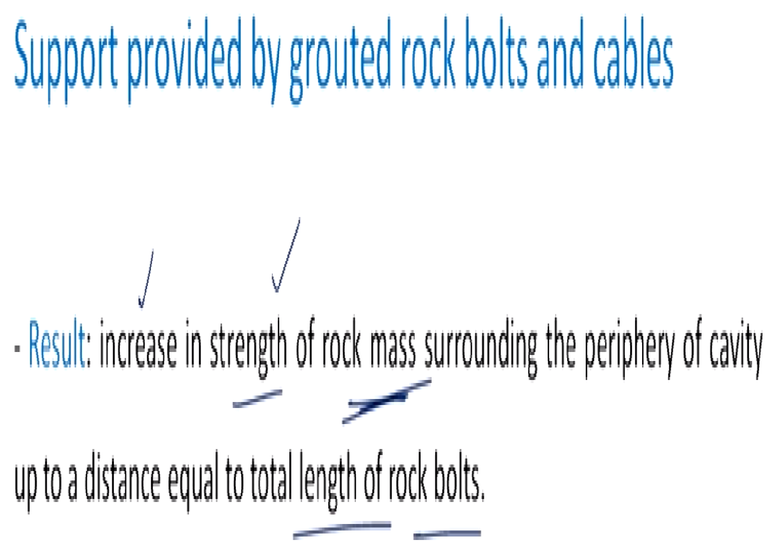

Now, what happens after the provision of the grouted rock bolts the rock mass becomes reinforced. So, in that case, your Q, which is improved this will be more than Q prime. So, there is going to be the improvement in the values of m and s, and let us say that they become m prime and s prime. So, what happens after the installation of grouted rock bolt? The dilation of rock mass is not possible.

So, because of that what will be the result? There is going to be an increase in the strength of the rock mass surrounding the periphery of the gravity up to the distance, which is equal to the total length of the rock bolt. Because, basically with the help of these rock bolts, the rock mass is knitted together or it is stitched together. So, we have the overall increase in the characteristic of the rock mass.

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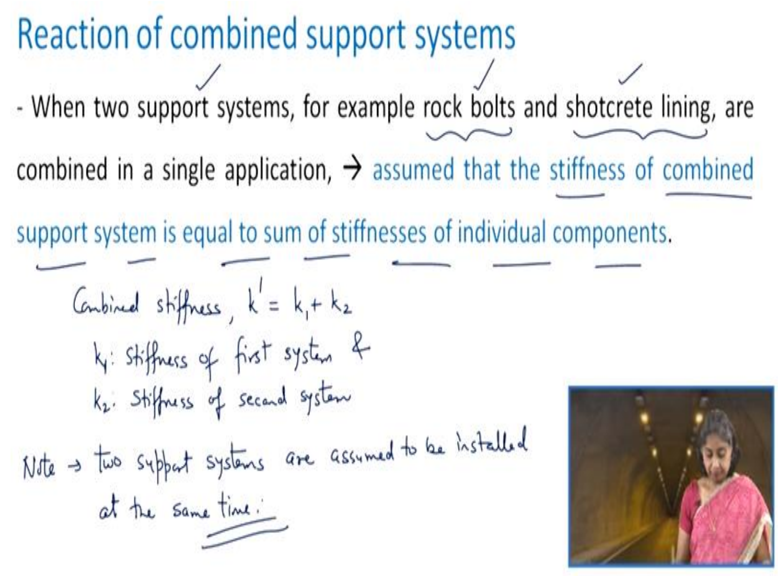

Now, what happens when you have the 2 types of support systems or when we talk about the combined support system? So, there the example of such a combined support system can be say the combination of shotcrete plus the rock bolt or maybe the concrete layer and the rock bolt. So, how to handle such type of situation? What will be the stiffness when we go for the combined support system?

So, when you have the 2 support systems and for example let us take, that we have rock bolts and the shotcrete lining they are combined in a single application. What this means is that, you have the tunnel where you provide shotcrete lining as well as the rock bolts. So, here we assume that the stiffness of the combined support system is equal to the sum of stiffnesses of the individual component.

So, let us say that we have rock bolts and shotcrete lining. So, what will be the stiffness of the combined support system it will be the stiffness of the rock bolts plus the stiffness of the shotcrete lining, which we already have obtained individually. So, how we are going to write it? So, we have the combined stiffness which is

$k' = k_1 + k_2$

Where this k1 is the stiffness of the first system and k2 is the stiffness of the second system.

Here, you need to take note that both systems should be installed simultaneously. So, we have to take note here, that 2 support systems are assumed to be installed at the same time. We need to keep this in mind.

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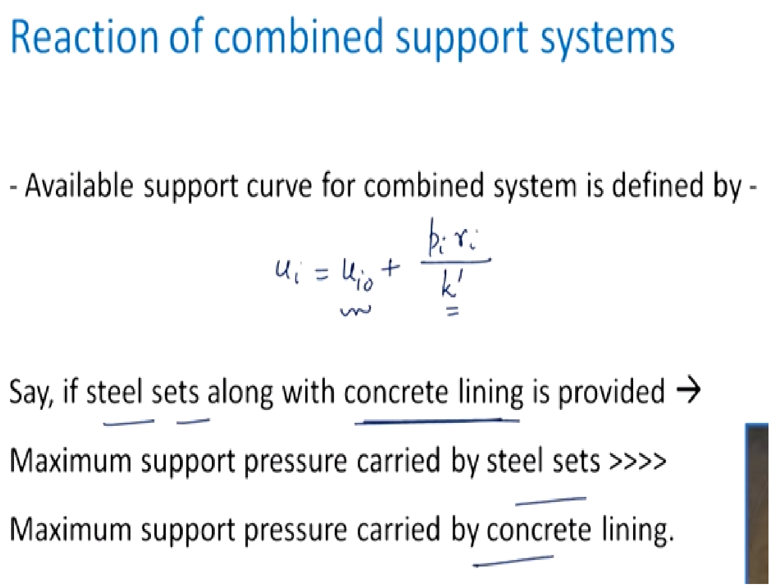

So, what will be the available support curve for the combined system? This is defined by

$$u_i = u_{io} + \frac{p_i r_i}{k'}$$

You must be familiar with this expression we derived in the previous class, where u_{io} is the initial deformation that is allowed and k prime here is the stiffness of the combined support system. So, let us say that if the steel sets are provided along with the concrete lining then what will happen?

The maximum support pressure which is carried by these steel sets, it is much larger as compared to the maximum support pressure which can be carried by the concrete lining.

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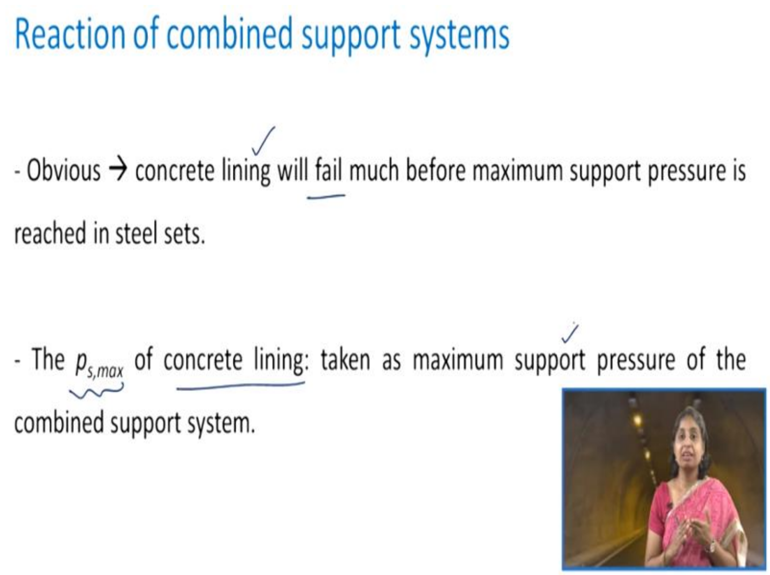

So, what then we need to see that, therefore, then it will be very obvious that the concrete lining, will fail much before the maximum support pressure is reached in steel sets. And hence this $p_{s\,max}$ of the concrete lining will be taken as the maximum support pressure for the combined support system. So, here I am taking the example of the concrete lining and the bolts. But let us see if you have any other type of or any other combination of the support system.

Please remember, that whichever system has a low value of the maximum support pressure that will be treated as the maximum support pressure of the combined support system.

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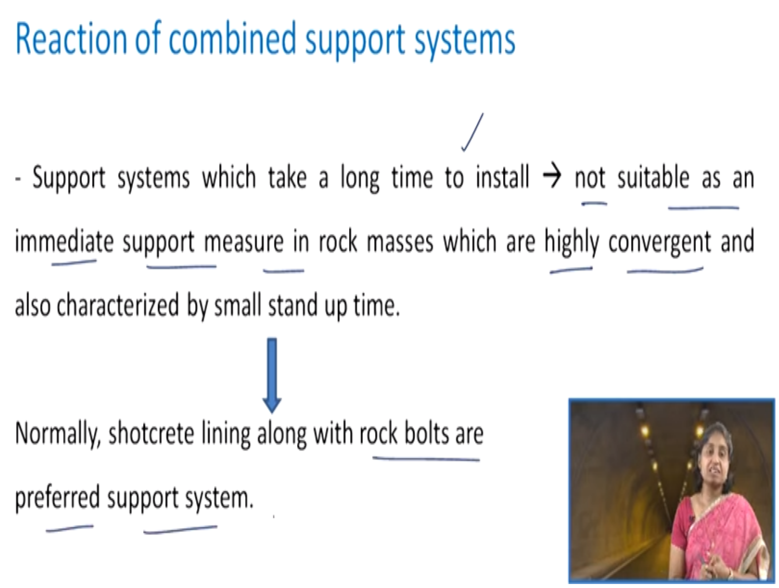

Now, the support systems which take a quite long time to install are not suitable as an immediate support measure in the rock masses which are highly convergent and also characterized by small stand-up time. So, in such cases normally the shotcrete lining along with the rock bolts are provided as the preferred support system.

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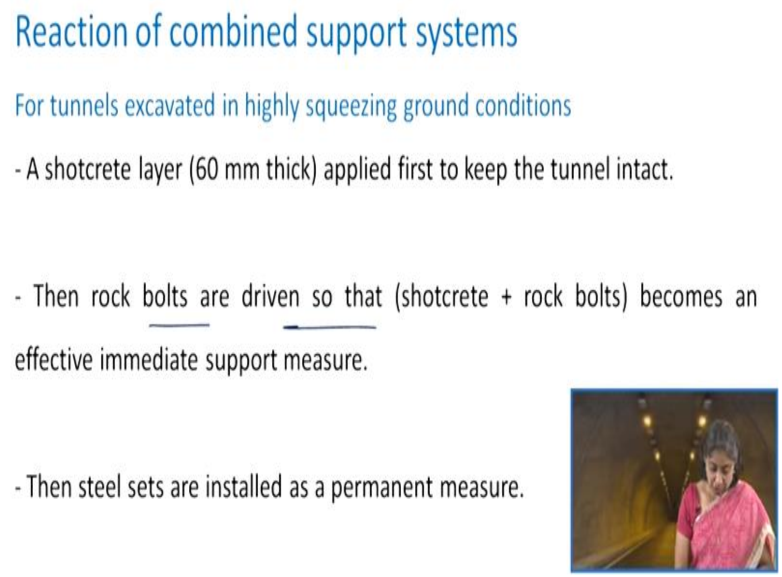

And, the cases where the tunnels are excavated in highly squeezing ground conditions. What do we do? We first apply a shotcrete layer of about 60 mm thickness to keep the tunnel intact immediately after the excavation and then the rock bolts are driven. So, both the support system that is the shotcrete and the rock bolts become an effective immediate support pressure and then we install the steel sets as a permanent support system.

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Reaction of combined support systems

If such tunnel is supposed to carry water under pressure:

- Further, a concrete lining is applied to make the tunnel surface smooth.

- Stiffness of the combined support system → comprise of stiffnesses of individual support system.

Now, if such tunnels are expected to carry the water under pressure. Then what we need to do is? We further provide the concrete lining, to make the tunnel surface smooth. So, when it is carrying the water the forces, which are generated with the pressure that the water is exerting reduces, if the tunnel surface is smooth. So, the stiffness of the combined support system is comprised of these stiffnesses of the individual support system please note this.

This, so, this was all about that how the maximum support pressure for the combined support system can be considered and how we can determine the stiffness? In the next class, we will study few more aspects related to the Ladanyi's analysis for the interaction phenomena of the rock mass and, the tunnel support. And, we will also see that, what all are the various calculation steps and the sequence, all these things, we will discuss in the next class. Thank you very much.