Rock-Support interaction analysis
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Module No # 10
Lecture No # 46
Rock – Support Analysis: Available Support for Shotcrete/Concrete Lining & Blocked Steel Sets

In the previous class, we discussed about the support reaction curve in connection with the rock mass tunnel support interaction analysis by ladanyi's analysis which is the elastoplastic analysis. So, the question was there in the previous class that, how to decide the stiffness of various support systems. So, there are various Expressions, which are given for different support systems. So, today we will focus on 2 types of the support system.

The first one is shotcrete or concrete lining and, the second one that we will discuss is about the blocked steel sets. So, here first let us take a look about the available support for concrete or shotcrete lining, everybody knows about the concrete coming to this term shotcrete. It is the slurry, which is 5 tired under pressure on the rock mass surface. This slurry is made up of cement sand, and, finite aggregate mixture

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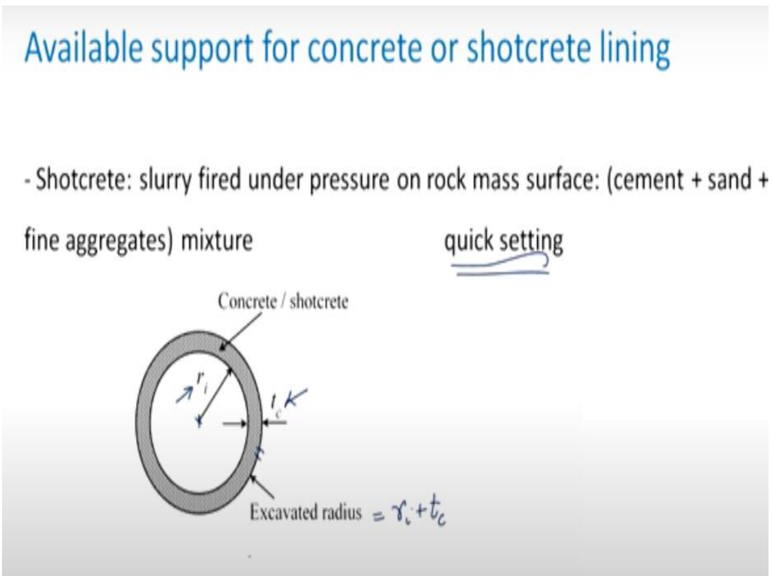

And, it is the quick setting one, so how it looks like, as far as the cross-section of the circular tunnel is concerned. So, if we have this as the excavated radius and, we apply a layer of concrete or shotcrete and say the thickness of this layer is t_c, then the inner radius which is the completed radius or the final radius of the tunnel that is r_i, so basically, the excavated radius is r_i + the thickness of t concrete or the shotcrete layer.

So, after the application of concrete or the shotcrete layer, this is how the system looks like in the cross-section.

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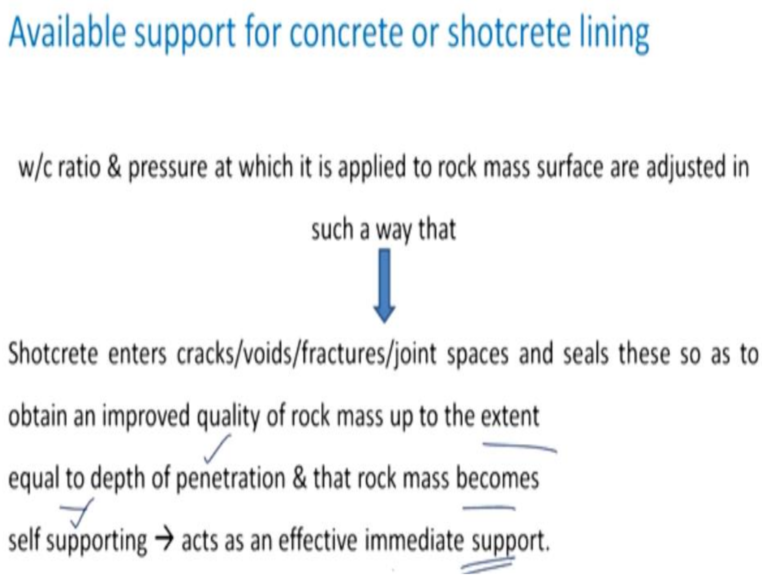

What about the water-cement ratio and the pressure at which it is applied to the rock mass surface, so, these 2 quantities, they are adjusted in such a way that the shotcrete enters into the cracks, voids or fractures, or joint spaces which are present in the rock mass and then it goes inside and sets there to seal these, such that you get an improved quality of rock mass but then what will be the extent of this improved quality of the rock mass.

That will depend upon to what extent this shotcrete can enter into the rock mass through cracks voids or fractures or joint spaces. So, basically, the extent will be equal to this depth of penetration and the rock mass up to that extent may become self-supporting and the result of this is that, it acts as an immediate and very effective support system so in most of cases, as soon as you excavate the tunnel.

You just lay a layer of shotcrete or spray a layer of shotcrete and, it provides the immediate effective support.

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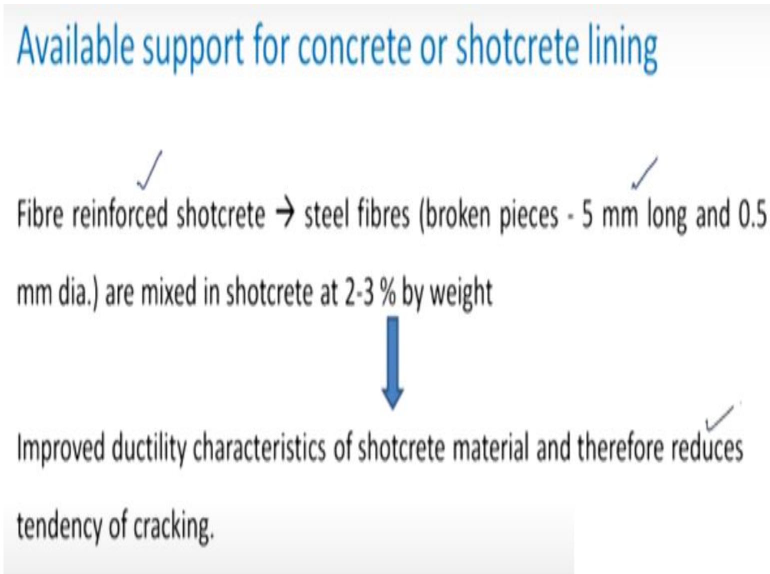

Sometimes these steel fibers are mixed in the shotcrete by 2 to 3% of the weight this is called as fiber reinforced shotcrete. So, these steel fibers basically, these are the broken pieces which are 5 millimeter long and, they are in 0.5-millimeter diameter. So, when you mix these in the shotcrete at 2 to 3% by weight, what happens is that, their ductility characteristic increases. So, what happens is that the ductility characteristic of the shotcrete material increases, and hence the tendency of the shotcrete for cracking, it reduces drastically. So, sometimes we go for the fiber-reinforced shotcrete to reduce the tendency of cracking of shotcrete alone.

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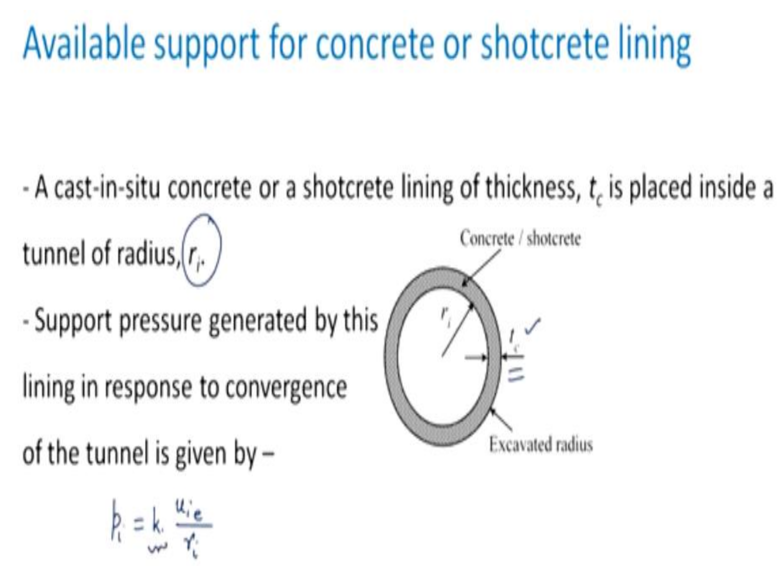

So, the case since to a cast-in-situ concrete or a shotcrete lining of thickness Tc, which is shown here in this figure is placed inside the tunnel and the final radius of the tunnel is ri. So, what will happen to the support pressure which is generated by this lining in response to the convergence of the tunnel? So, this is given by this expression

$p_i = k \left(\frac{uie}{ri}\right)$

So, what about k?

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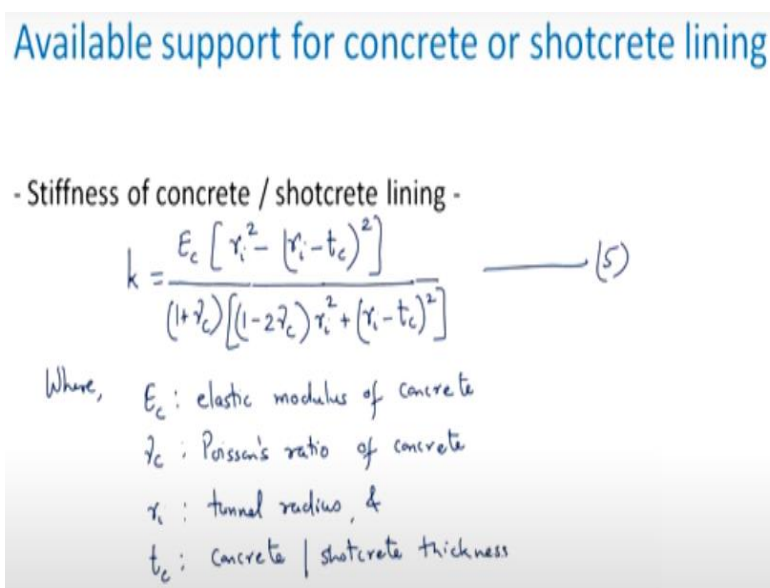

This is the stiffness of concrete or shotcrete lining and it is given by this expression which is

$$k = \frac{E_c(r_i^2 - (r_i - t_c)^2]}{(1 + \gamma_c)[(1 - 2\gamma_c)r_i^2 + (r_i - t_c)^2]}$$

I will mark this equation as equation number 5 in continuation with the previous class where the various terms which are mentioned in equation number 5. They are given as E_c as the elastic modulus of concrete or shotcrete then γ_c is the poisons ratio of concrete, r_i is the tunnel radius and this t_c is concrete or shotcrete thickness.

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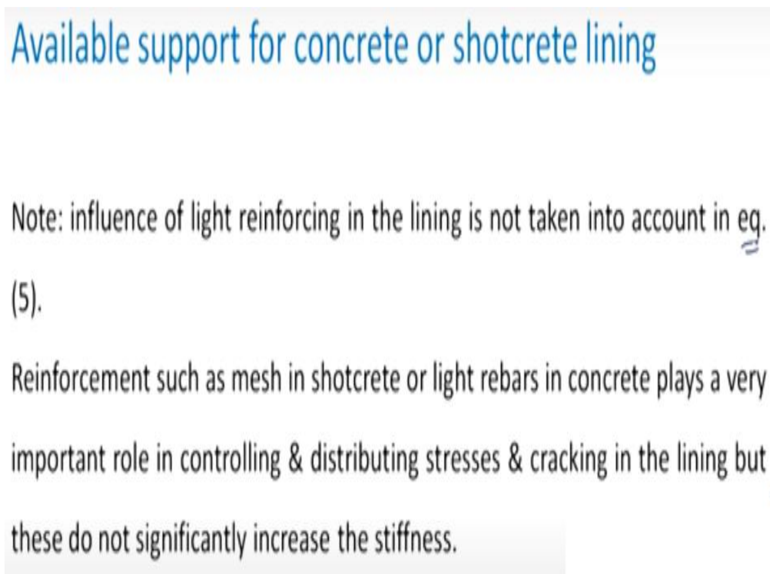

Now, we need to keep this in mind that, the stiffness which is given by this equation number 5, which we just now discussed, it does not take into account the influence of light reinforcement in the lining, may be in the form of the fibers or the mesh. See, what happens is sometimes after the excavation first a mesh is laid all along the periphery of the excavation and then, the shotcrete layer is sprayed.

But then, the stiffness expression does not account for such type of light reinforcement, so, the function of such reinforcement which is mesh in the shotcrete or maybe light reinforcement bars in concrete. They play an important role in controlling and distributing the stresses and, reducing the cracking in the lining. However, they really do not increase the stiffness of the shotcrete or the concrete layer significantly. Therefore, it is reasonable to assume that, there is no influence of this light reinforcement in the lining as far as the stiffness of the shotcrete or the concrete lining is concern.

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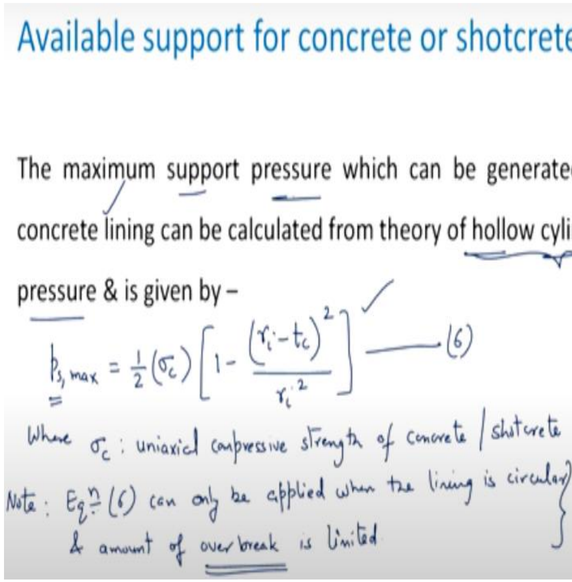

Now, we learned about the stiffness of the support system what about its maximum support pressure which is $p_{s,max}$ in the previous class, we saw that this particular term is very important and we should know this along with the stiffness of the support system. So, the maximum support pressure that can be generated by a shotcrete or the concrete lining this can be calculated from the theory of hollow cylinders under external pressure.

And is given by this equation which is

$$p_{s_1 max} = \frac{1}{2}(\sigma_c)[1 - \frac{(r_i - t_c)^2}{r_i^2}]$$

Square bracket close make it equation number 6, so, where this σ_c is the uniaxial compressive strength of concrete or shotcrete. whatever that you have applied so here we need to take a note that the equation 6 can only be applied when the lining is circular and, the amount of over break is Limited.

In one of the previous classes, I mentioned to you that what exactly you mean by this over break kindly take a note that, we have obtained this $p_{s,max}$ from the theory of hollow cylinders under external pressure. So, in case, if the cross-section is not circular this expression will not be applicable, so, here one limitation is there when we find out the maximum support pressure which is generated by a shotcrete or the concrete lining.

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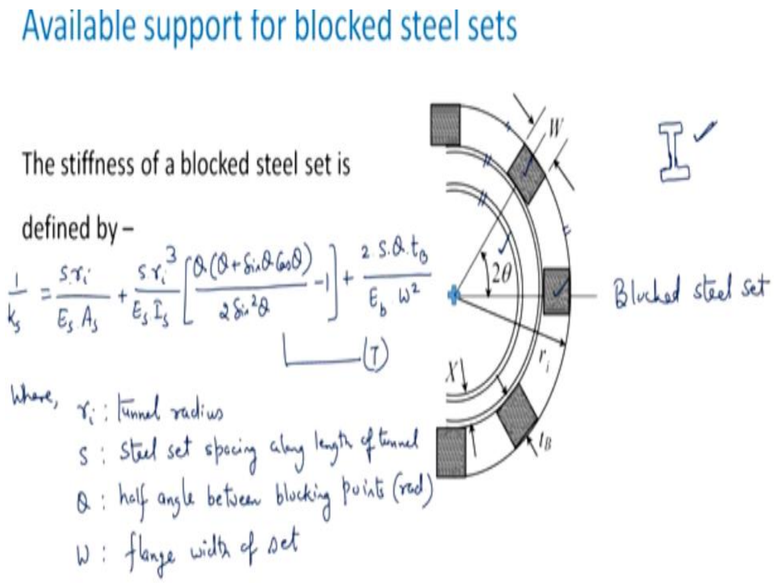

Now, coming to the available support for the blocked steel sets, so, why do we call it as block steel set, so you see that this is the tunnel periphery and, you provide these steel sets having this kind of cross-section may be the eye section. Then, what is the need of providing this block, so you see when you have the excavated periphery. It is never going to be smooth and, when you try to install these steel sets all around the periphery of the tunnel.

These steel sets may not be in perfect contact with the excavated surface. So, therefore, these blocks are provided to have the proper contact between these steel sets and this excavated periphery, so, basically, these 2 sets of Curves, they are nothing but this type of the section of the Steel set, this, we will discuss in detail, little while, but then let us first focus on the stiffness of a blocked steel set.

Which is defined by this expression, which is

$$\frac{1}{k_s} = \frac{sr_i}{E_sA_s} + \frac{sr_i^3}{E_sI_s}\left[\frac{\theta(\theta + \sin\theta\cos\theta)}{2\sin^2\theta} - 1\right] + \frac{2s\theta t_B}{E_b\omega^2}$$

I will mark this as equation number 7. Now there are so many terms, let us take a look one by one that, what all these are so where first of all this r_i which is the tunnel radius.

The second one is S, so this is the steel set spacing along the length of the tunnel, then, θ is the half angle between the blocking points and this is in radian, so, keep this in mind so you see that here this is one blocking point this is another blocking point, so, the angle that these two blocking points they are subtending at the center of the excavation which is given as 2θ , so, therefore, we are writing this Theta as the half angle between the blocking points. Then w flange, width of the steel set, so basically, this is showing you the view of blocked steel set.

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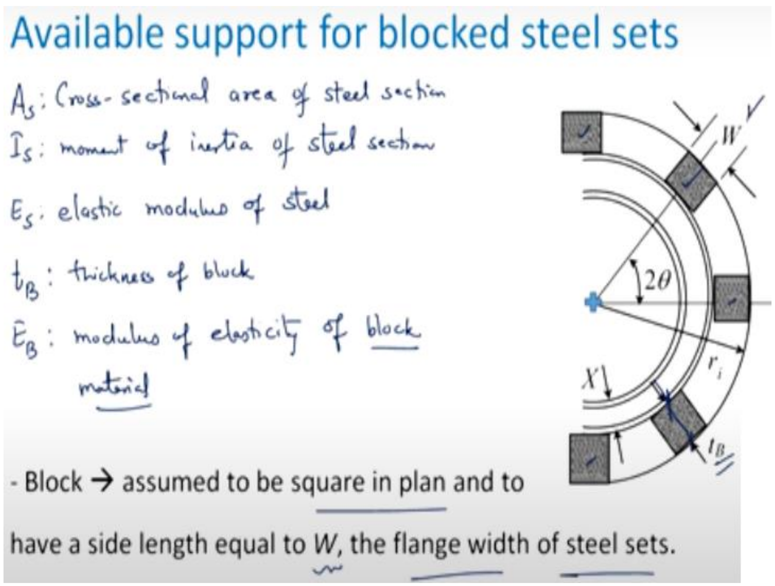

Now, the other parameters include as, As the cross-sectional area of steel section, so, you see that if you are going for, let us say I shape of the steel set so this as is going to be the cross-section area of that eye-shaped set, then Is is the moment of inertia of Steel section Es is the elastic modulus of steel then t_B is the thickness of block so, you see here, this thickness of the block means this distance.

Which is shown here this one which is t_B then we have another term as E_B which is the modulus of elasticity of block material now as far as these block material is concerned all these are blocks as has been shown in the figure, so as far as the blocks are concerned, these are assumed to be square in plan and these have a side length which is equal to W, which I just mentioned that it is the flange width of the steel sets, which is shown here in this figure.

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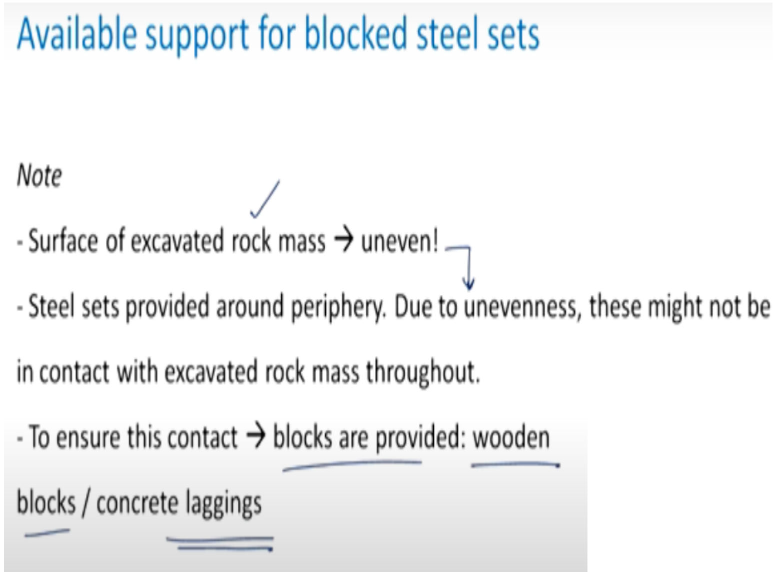

You need to take a note here that the surface of the excavated rock mass is highly uneven, so, when we provide these steel sets these are provided all around the periphery and, because of this unevenness, these, might not be in contact with the excavated rock mass throughout the periphery? So, to ensure this contact the blocks are provided, which can be either the wooden blocks or the concrete laggings.

So, the reason is that if this contact is not properly achieved then there is going to be the gap between the excavated rock mass and, the support system and the efficacy of the support system will reduce drastically if, there is no contact between the excavated rock mass surface and the support system so we have to go for the provision of these blocks.

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Available support for blocked steel sets

Concrete laggings:

- Length is equal to c/c spacing of steel sets along length of the tunnel & cross-sectional dimensions are usually 100 mm × 100 mm.

Now coming to these concrete laggings usually these day wooden leggings they are not provided concrete leggings they are provided so that their length is equal to the center to Center spacing of these steel sets along the length of the tunnel and the cross-sectional Dimension, as I mentioned that it is square in shape, so the dimensions are usually 100 mm by 100 mm. So, you see that if this is the length of the tunnel and, you provide one steel set here and there is going to be another steel set at some center-to-center spacing.

So, if these are the 2 steel cells the concrete lagging is provided along the length of the tunnel having the length is equal to Center-to-Center spacing of T Steel sets

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Available support for blocked steel sets

Maximum support pressure which can be accommodated by steel sets –

$$p_{s,max} = \frac{3 A_s \cdot I_s \cdot \sigma_{ys}}{2 S \cdot r_i \cdot \theta \left[3 I_s + x A_s \left\{ r_i - \left(t_B + \frac{1}{2} x\right)\right\}(1 - \cos\theta)\right]} \quad \text{——— (8)}$$

σ_{ys} : yield strength of steel

x : depth of steel section

Now, coming to the maximum support pressure which can be accommodated created by the steel sets, so, this is what is the expression for this which is

$$p_{s,max} = \frac{3.A_s.I_s.\sigma_{ys}}{2.s.r_i.\theta[3I_s + xA_s\{r_i - (t_B + \frac{1}{2}x)\}(1 - \cos\theta)]}$$

I will write this equation as equation number 8. Where, the σ_{ys} is the yield strength of the steel and x is the depth of the steel section.

So, let me take you to the figure here, so, what is going to be this x so, it is the depth of this steel section, so, you see that the steel section if it is of eye shape, so, basically this is what is going to be the dimension X, so, let me make it as small x here. So, this is how you can determine the stiffness, as well as the maximum support pressure for these steel sets, so, today we learned about the stiffness and the maximum support pressure for shotcrete or concrete and these steel sets.

But then, there are other types of the support systems, such as rock bolts, so, in the next class, we will learn similar expressions that are for the stiffness and, the maximum support pressure for the rock bolts, in the next class, thank you very much.