Rock Engineering

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Lecture - 47
Rock Mass Support Interaction Analysis - 02

Hello everyone, in the last class, we learned about the concept of rock mass tunnel support interaction analysis. I introduced you 2 curves, one was ground response curve and another was support reaction curve. And I explained you that how you can obtain these 2 curves with the help of few examples, which were two dimensional in nature. Today, we will see how exactly this happens in the field with respect to a three dimensional example of a tunnel construction. Let us try to see this we have this three dimensional condition.

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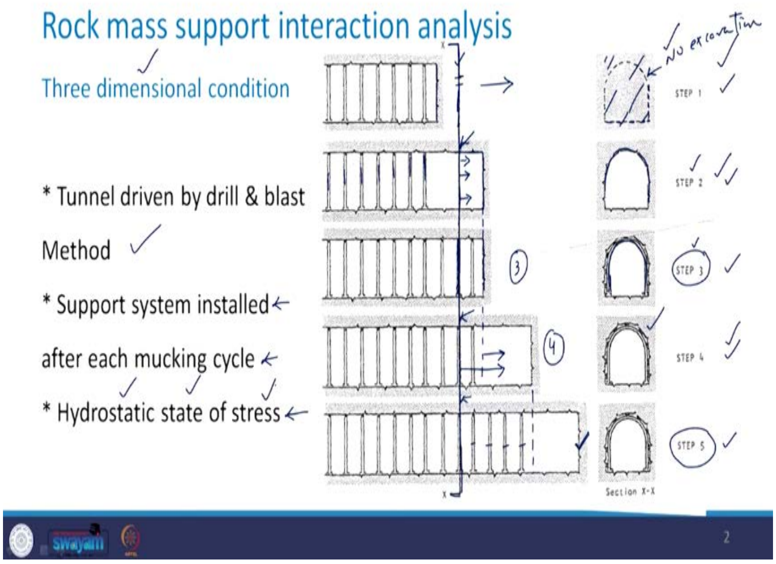

And take a look at this figure and try to understand this carefully. I have taken a section X-X, this one. The tunnel is advancing in this direction. So, there are various steps in the construction of the tunnel such as Step 1, Step 2, Step 3, 4 and 5. In the Step 1, the tunnel face which is this has not yet reached to this section X-X. And if you just cut it across it this section X-X, this is what that you are going to look for that.

Here it is all the rock mass is there and is still at section X-X. There is no excavation. And that is the reason that the outline of probable excavation has been shown with the help of the dotted lines. Then, the tunnel advances. And you can see that you reach to Step number 2, where the tunnel has advanced beyond this section X-X. That means tunnel face which is this face is now beyond the section X-X.

And these vertical lines these show the support system which have already been installed. So, here the tunnel has been advanced beyond the section X-X, but the support system has not yet been installed here at this section. Come to the next step, which is Step number 3. Tunnel has been advanced up to this point only which was there in case of the Step 2 as well. But now, what is a difference between Step 2 and Step 3 is that now at section X-X the support system has been installed.

So, what you see in the cross section is along with this tunnel excavated surface. You have here the support system which has already been installed here. Then, in the Step 4, tunnel has been further advanced. So, you see earlier it was up to this much. Now, it has been further advanced. So, what you will see at the cross section of this section X-X is the same view, but what is a difference between Step 3 and Step 4 is that, that now the tunnel has been advanced further from the section X-X.

In case of the Step 5, whatever was the excavation up to Step 4, all the support systems have been installed up to that plus the tunnel face has been further advanced. So, these are the 5 steps that we are going to discuss in detail with reference to the generation of GRC and SRC. Before I go to that, we need to keep these few points in mind that the tunnel is driven by drill and blast method. Support system is being installed after each mucking cycle.

That means you advance the tunnel to some distance, whatever is the muck material that is the result of this process of advancing the tunnel. It should be removed. And then the support system is installed in that excavated region. The third condition is it is assumed that there exists the hydrostatic state of stress. This means that the horizontal as well as the vertical stresses they are same.

Now, let us try to understand the generation of GRC and SRC with respect to each of these steps in detail. So, I first take the Step 1. So, here from the previous figure, I have just taken out the figure which corresponds to Step 1.

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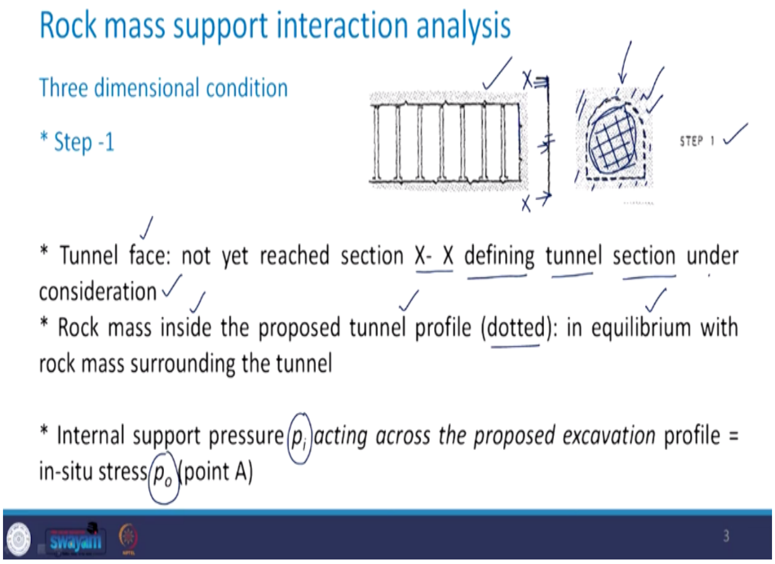

Once again, this is your X-X section. And the tunnel face has not yet reached up to this section. That means it is here only. So, if you just take a cross section or take a section at X-X and try to look in this direction, what you will see is the intact rock or the rock mass through which the tunnel is being excavated. So, in this case, the tunnel face has not yet reached the section X-X which is clear from this figure, which is defining the tunnel section under consideration.

That means, whatever are the tunnel sections that we are seeing in different steps in this particular form, they are the view of the tunnel about this section X-X which is constant with reference to the advancement of the tunnel. Then, rock mass which is inside the proposed tunnel profile that is, this one. So, this is because it has not yet reached up to the section X-X. So, this is shown as the dotted portion.

So, whatever is the rock mass which is here inside this dotted section, this is in equilibrium with the rock mass which is surrounding the tunnel that means, that the rock mass which is here inside this portion is in equilibrium with whatever is outside here and therefore, the internal support pressure which I am representing with p_i will be acting across the proposed excavation profile. That will be equal to the in-situ stress p_0.

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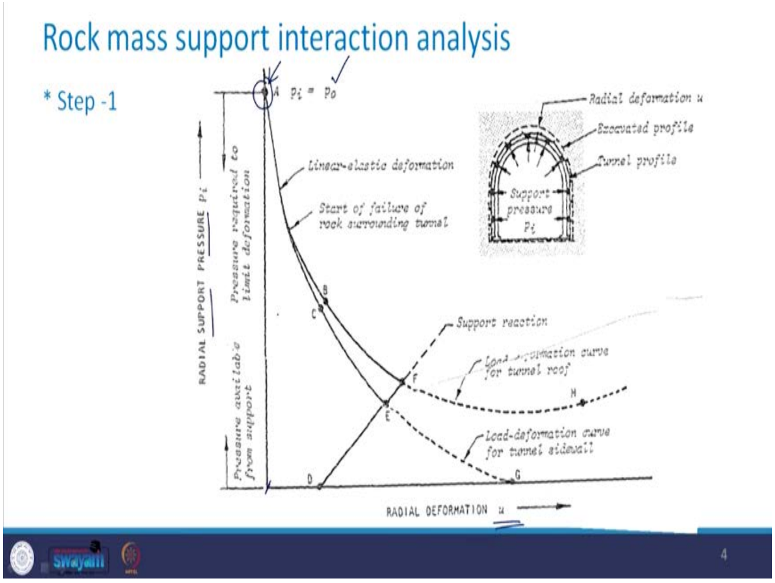

And this is represented with the help of a point A where we are trying to plot the radial support pressure versus the radial deformation. Now, please recollect our discussion of the last class where I explained you these concepts with the help of a two dimensional situation for competent rock for incompetent rocks as well. So, here, the first point is going to be the point A. And here your p_i will be equal to p_0 which is the in-situ state of stress.

And since the rock mass has not been excavated at that section, and so, obviously, the radial deformation is going to be 0 in this case.

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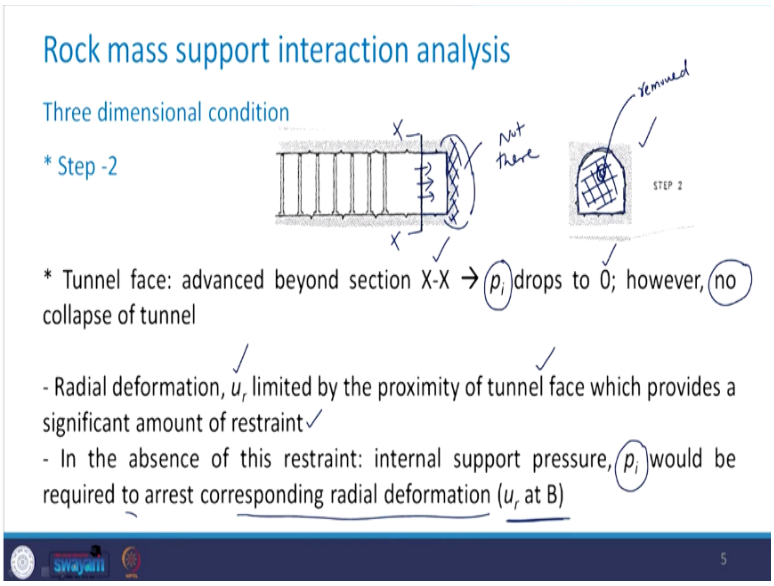

Come to the Step 2. So, this section X-X remains the same. But, now, the tunnel face has been advanced beyond this section X-X. So, how it will look like in this view? See here, so, the material which was there inside this proposed excavated boundary, now, this material has been removed. And the tunnel has been advanced this much further the section X-X. So, as I mentioned tunnel face has been advanced beyond section X-X.

This material has been removed. So, this boundary becomes a stress free boundary. And therefore, the internal pressure p_i it drops to 0. However, there is no collapse of the tunnel. This radial deformation u r will be limited by the proximity of tunnel face, which provides a significant amount of restraint. See, this section X-X is very much near to this face of the tunnel.

So, because here you have the rock or the rock mass through which the excavation has to take place. So, this rock mass here provides the sufficient amount of restraint. And therefore the radial deformation u_r is limited in this case. Now, in case if this restraint is not there, if it is not there, then what will happen is, you will need to have some internal support pressure p_i in order to arrest the corresponding radial deformation, which is say $\underline{u_r}$ at this point B which I will show you in the next figure.

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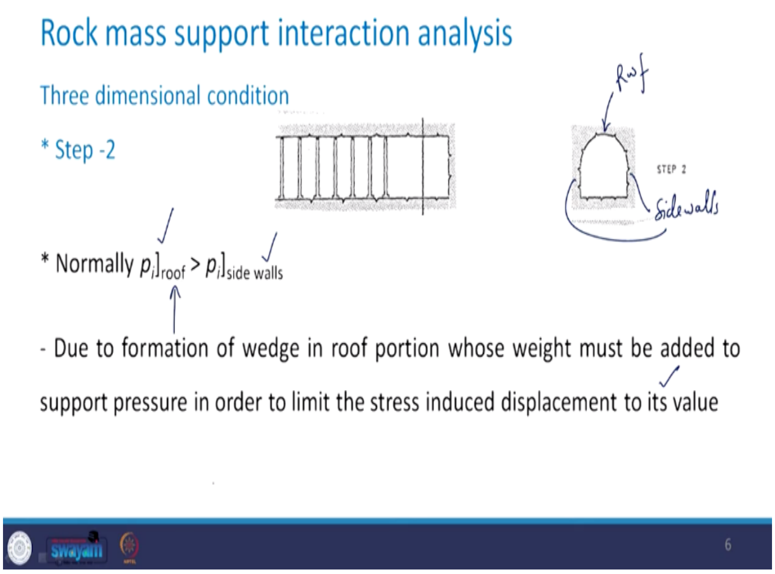

But before that, you see here we take the same step. And we have 2 portions of the tunnel, one would be the roof and another would be the sidewall. That is this is what is your roof and these are going to be your sidewalls. So, normally this support pressure for case of the roof is more than that for the sidewalls. This is due to the formation of wedge in the roof portion whose weight must be added to the support pressure in order to limit the stress induced displacement to its value.

So, therefore, you get such type of situation that p_i for roof is always more than p_i of the sidewalls.

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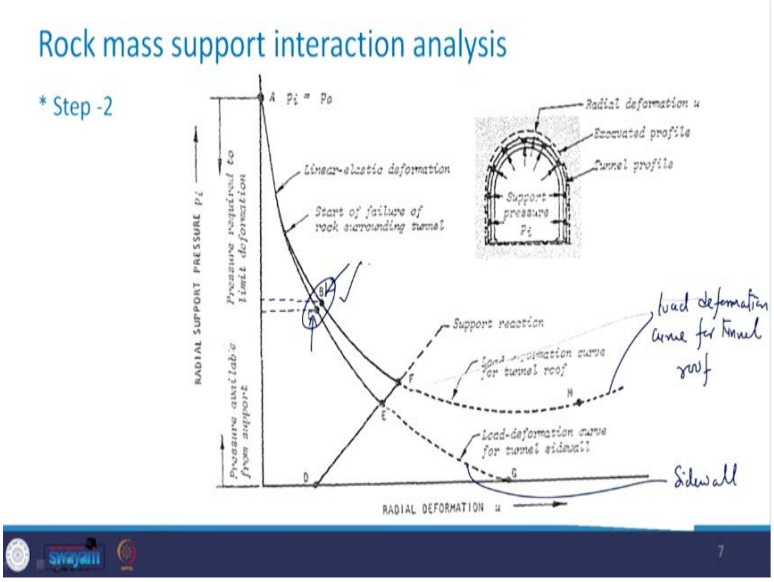

So, in this case, you see that here, this will correspond to these 2 points B and C. Now, take a look here that the upper portion of the curve that is this one is the load deformation curve for the tunnel roof and the lower one is for the sidewall. So, this point B corresponds to roof and point C corresponds to sidewall. And you can see that if I take the pressure then p_i corresponding to B is larger than p_i corresponding to C.

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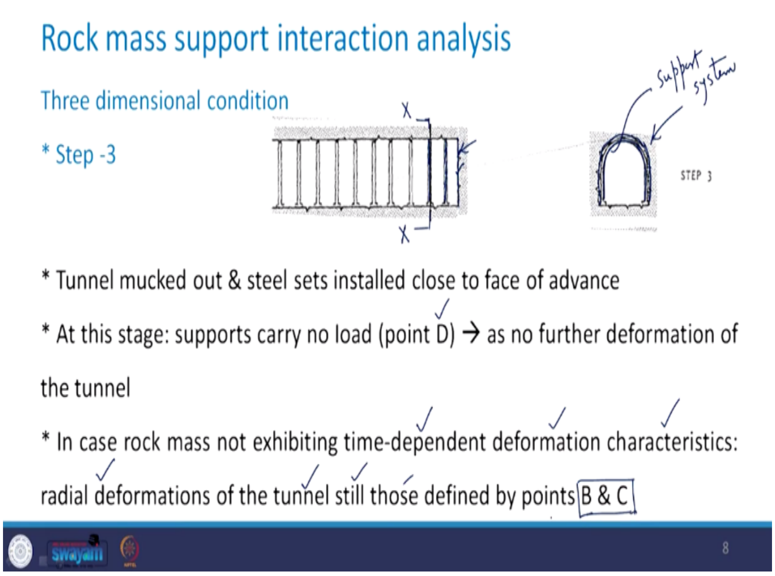

Now, come to the Step 3, where the tunnel has not been advanced further from the Step 2. But, what has been done is that whatever was advanced up to Step 2, the support systems have been provided. So, at the section X-X, which is this one, now, the support has been installed. And therefore, in this view, you are seeing the support system as well. So, this was the excavated periphery the outer portion and this is the support system.

So, what has been done in this Step 3 is that tunnel has been mucked out and the steel sets are installed close to the face of advance. So, this is the face of advance and the steel sets are provided close to this face of advance. Now, at this stage the supports will not carry any load. So, this will be represented by point D in the corresponding figure. I will take you there in a short while.

Because, no further deformation of the tunnel is taking place due to the installation of this support system, which is in the vicinity of the tunnel face. In case of the rock mass not showing the time dependent deformation characteristic, these radial deformations of the tunnel will be still those which were defined by the points B and C of the Step 2.

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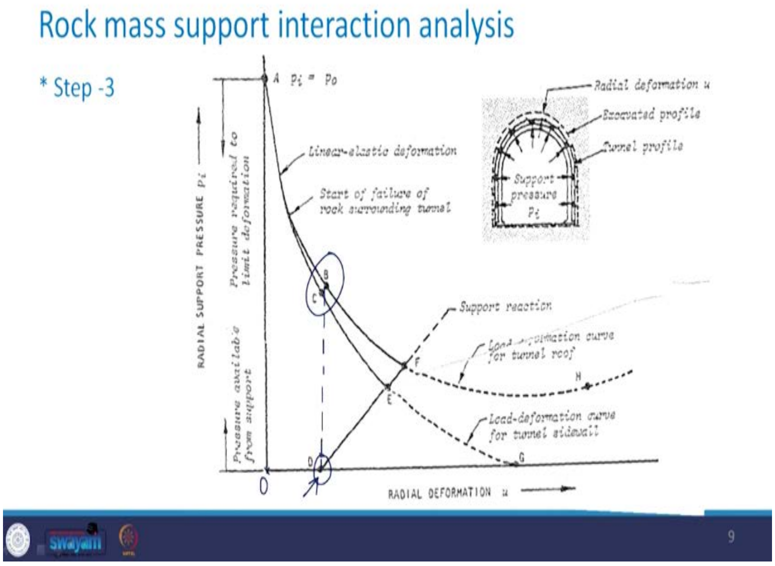

Take a look here. This corresponding to this, you have the deformation here corresponding to this point D. So, in case if there is no time dependent behavior of the rock or the rock mass, we are still here at this these 2 points. That is B and C. And see here at point D, you will not need any support pressure. So, here you see that it is starting from this point O. So, support pressure here corresponding to the point D is going to be equal to 0.

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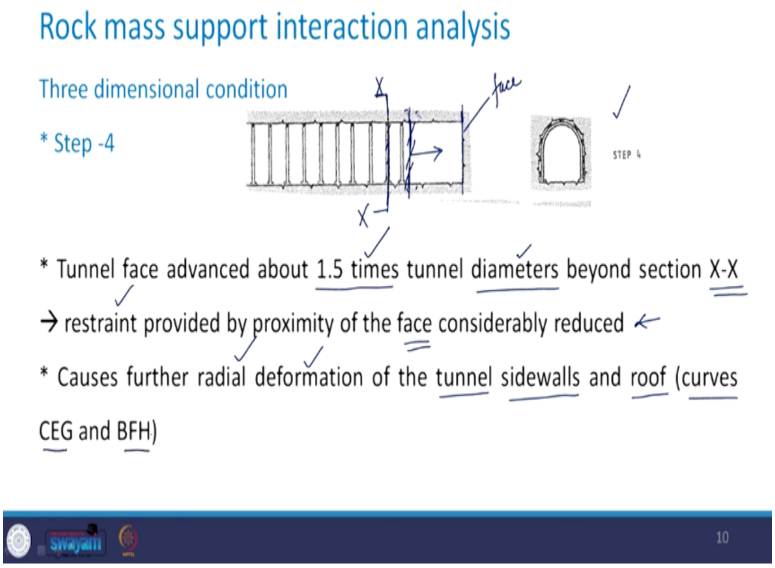

Now, coming to the Step 4, what has been done in this case is that beyond this section X-X the tunnel has further been advanced. So, this usually tunnel is advanced about 1.5 times the tunnel diameters in one face. So, the same thing has been done here that from the Step 3, the tunnel face was advanced about 1.5 times the tunnel diameters beyond the section X-X. Now, the view here from this section X-X will be same as it was there in case of Step 3.

So, the restraint which was provided by the proximity of the tunnel face, it considerably reduced. See earlier in Step 3, the tunnel face advanced was here. So, this section X-X was getting enough restraint because of the rock mass which was present in the vicinity of this tunnel face. But now, since this face has been removed and this face has reached to this location, so, the restraint which was there available at this section is no more available as the tunnel face has advanced to this particular location.

So, this causes further radial deformation of the tunnel sidewalls as well as the roofs. This is represented by curves CEG and BFH in this figure.

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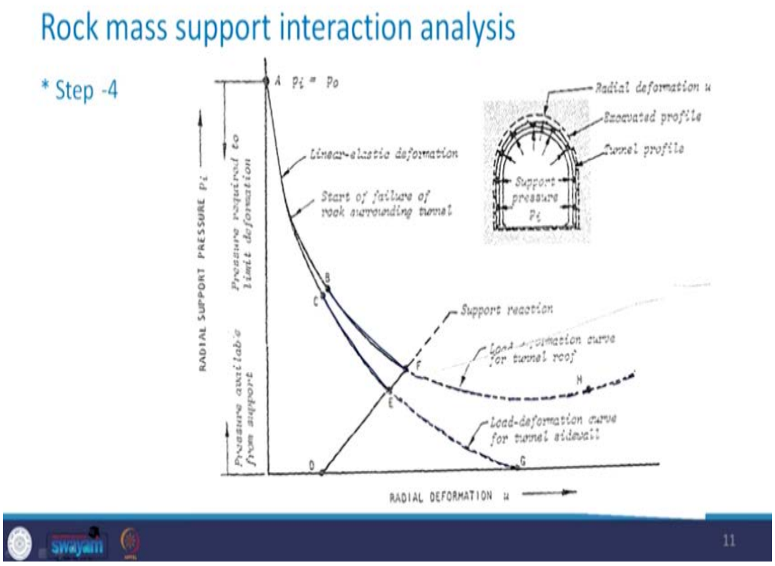

See here, this is CEG, this one and BFH. So, this is your B, this point is F and it goes beyond that. So, this is when there is no support system and the tunnel face has been advanced.

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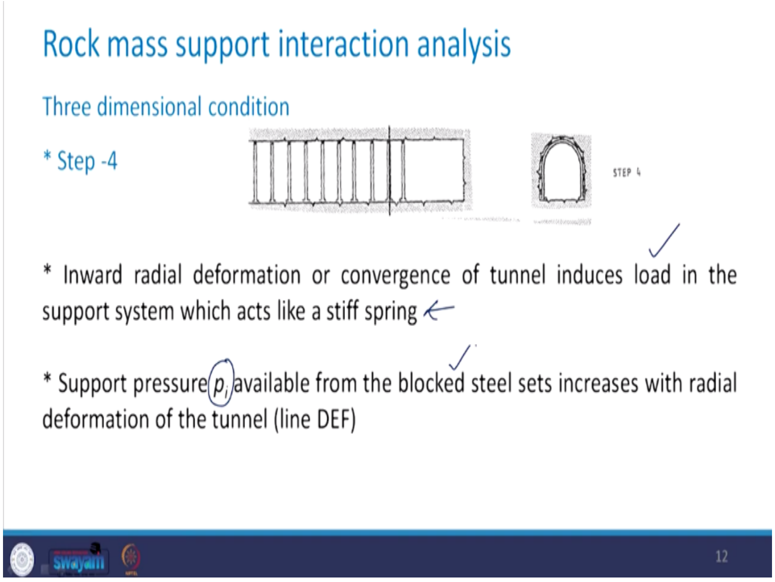

Now, in this case, the inward radial deformation or the convergence of the tunnel induces a load in the support system, which acts like a stiff spring. So, the support pressure p_i available from the blocked steel sets that increases with the radial deformation of the tunnel.

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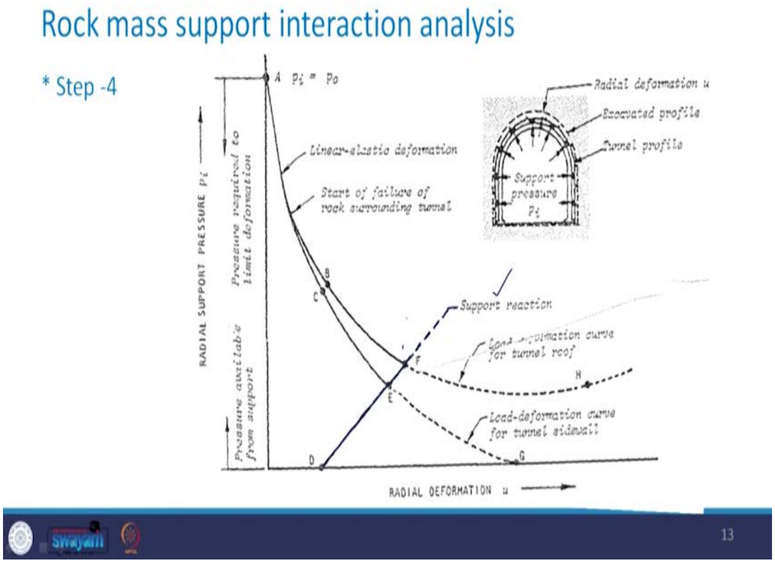

Take a look here that this is increasing from this point D in the manner this DEF. So, this is what is going to be the support reaction curve up to this much point. So, you see that how this GRC and SRC they are plotted simultaneously.

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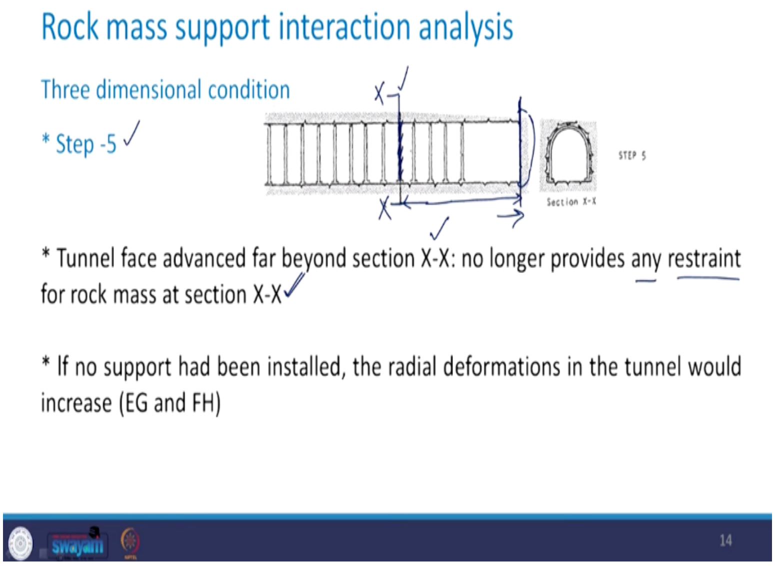

Coming to the next step, which is the Step number 5. And in this case, beyond this section X-X the support system has been installed and the tunnel face has been further advanced. And now, this face is much far than this section X-X. So, this tunnel face which is advanced far beyond the section X-X and no longer provides any restraint for the rock mass at the section X-X.

So, whatever was the restraint because of this presence of this tunnel face is no more available at the section X-X. Because this tunnel face is much further from the section X-X. Now, here in this case the support system has been installed at the section X-X. But assume a condition that if there is no support which has been installed, what will happen to the radial deformation of the tunnel? It will increase and that will result into these lines EG and FH.

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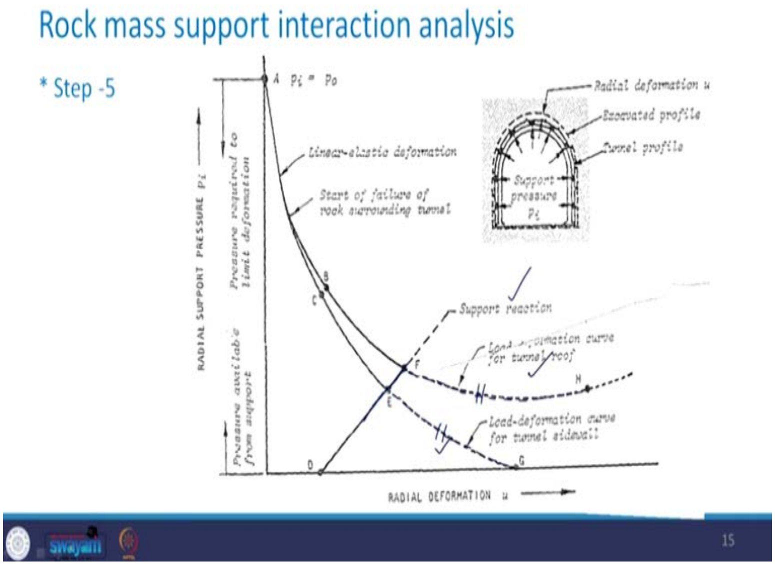

See here, if the support system is not installed, it will further increase in this particular manner for this is for the sidewall and this one is for roof like this. But then since we have installed the support system, so, these have got restricted here with the help of these support reaction. But in the absence of the support, this ground reaction curve is going to follow this part EG and FH for sidewall and for the roof respectively.

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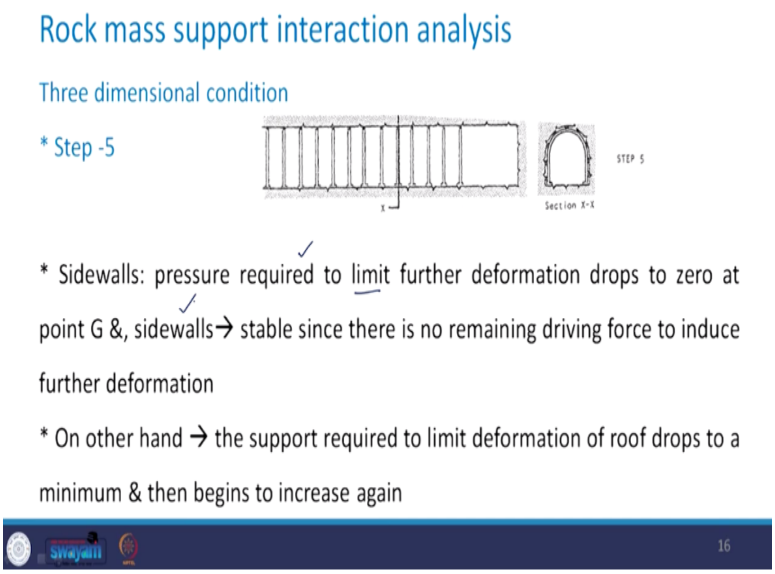

Now, these sidewalls, the pressure required to limit further deformation drops to 0 at the point G. And in case of the sidewalls, it will be stable since there is no remaining driving force to induce further deformation. On the other hand, the support required to limit the deformation of roof drops to minimum and then it begins to increase again.

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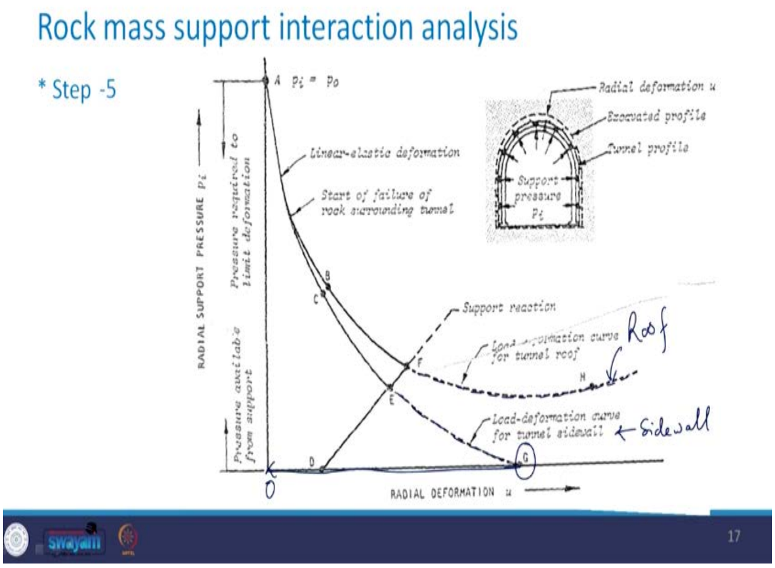

Take a look here. That in case of the sidewall, it follows this curve and becomes 0 at point G. So, that means here at point D, your internal support pressure it becomes equal to 0. But in case of the roof, which is this curve, see first it reduces and then it increases again.

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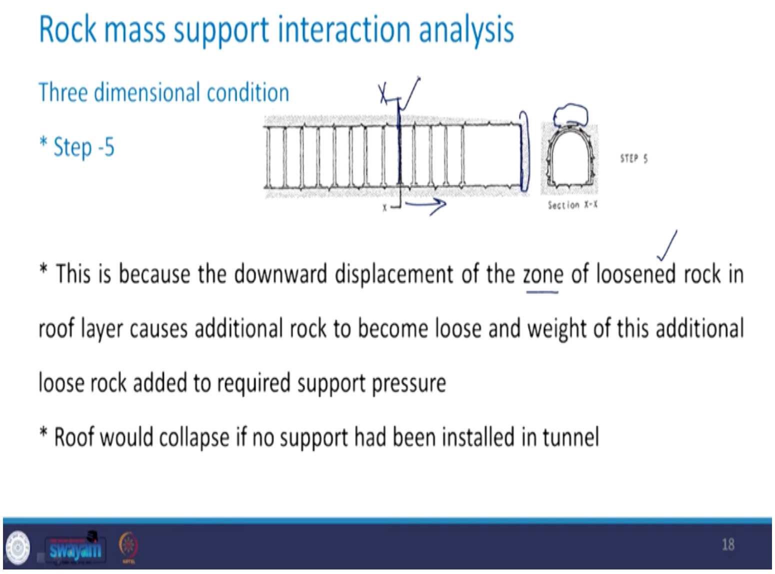

Now, what is a reason behind this kind of behavior that first it is reducing for the roof portion and then it is increasing? So, this is because the downward displacement of the zone of the loosened rock in the roof layer it causes additional rock to become loose. So, whatever was the mass in the vicinity of this excavated area, it gets loosened. And it also causes additional rock to become loose.

And the weight of this additional loose rock needs to be added to the required support pressure. Roof would collapse if no support had been installed in the tunnel. Therefore, the installation time of the support system in case of tunneling is very very important consideration. So, here the section is X-X. This tunnel face is much far than this X-X. There is no restraint because of the presence of this tunnel face at this section X-X.

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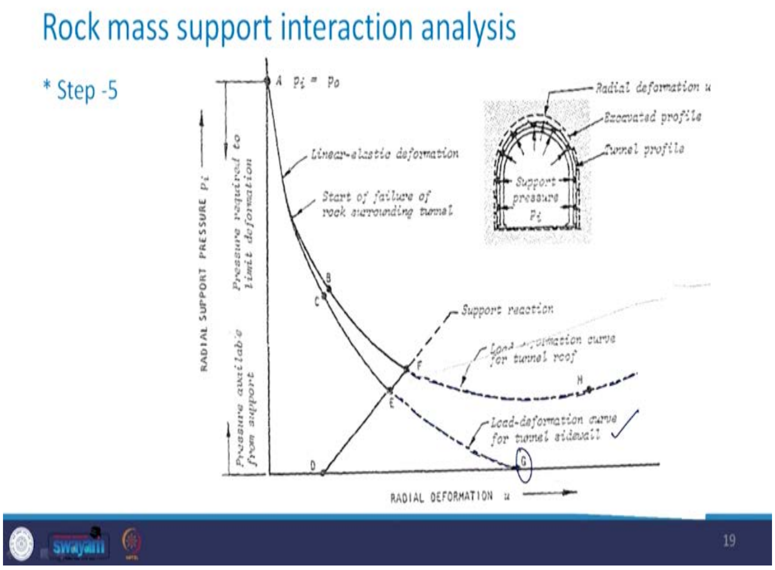

So, see here finally, what we will get for the roof portion, we will get this kind of the ground response curve. And in case of the sidewall here this is going to become equal to 0. Why? I just explained it to you.

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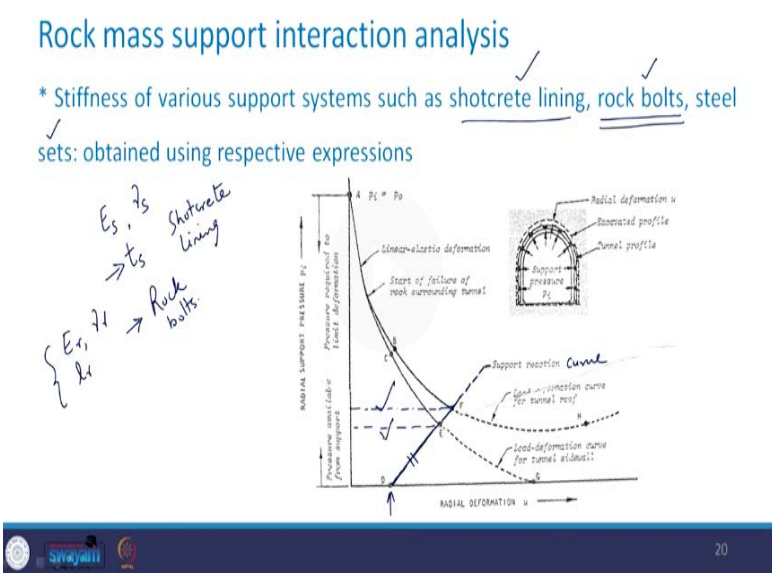

So, how to determine the slope of this curve that is representing the support reaction curve? There are various types of support systems which are available such as shotcrete lining, rock bolts, steel sets or then you can have the combination of these. These support systems can be designed based upon the requirement of the particular project. Now, the stiffness of these support systems can be determined.

If we know the property of the let us say we want to find out the stiffness of the shotcrete lining. So, if we know the property of this shotcrete lining let us say it is modulus is E_s and the Poisson's ratio is ν_s. And we know that the thickness of the shotcrete lining which is required is t_s. There are expressions which are used in order to determine the stiffness of this shotcrete lining.

Similarly, in case if you have to go for the stiffness of these rock bolts, so, what we need to know is again the properties of these rock bolts let us say E_r, ν_r. What is the length of the rock bolt that is required? So, if we know all these properties, the expressions are available in order to obtain the stiffness for the rock bolts. So, once we know the stiffness of these support systems, we can follow this support reaction curve.

And we can find out that what the deformation that can be permitted is and what is going to be the pressure which is being exerted on the support system in the roof as well as the sidewall portion. So, this is what I wanted to discuss with you as far as the rock mass tunnel support interaction analysis is concerned. So, this finishes our discussion on the chapter where we learnt one of the application area of the rock engineering and that is tunneling.

So, we learnt about the elastic analysis, elasto-plastic analysis and then the elastic analysis of the concrete lining. And then we saw the application of the stereographic projection in order to determine the shape and the size of the wedge which are formed in rock and the sidewalls of the tunnel. And then we learnt about the concept of rock mass tunnel support interaction analysis.

Now, in the next class, we will take up the next application area of the rock engineering, which is the rock slope stability. Thank you very much.