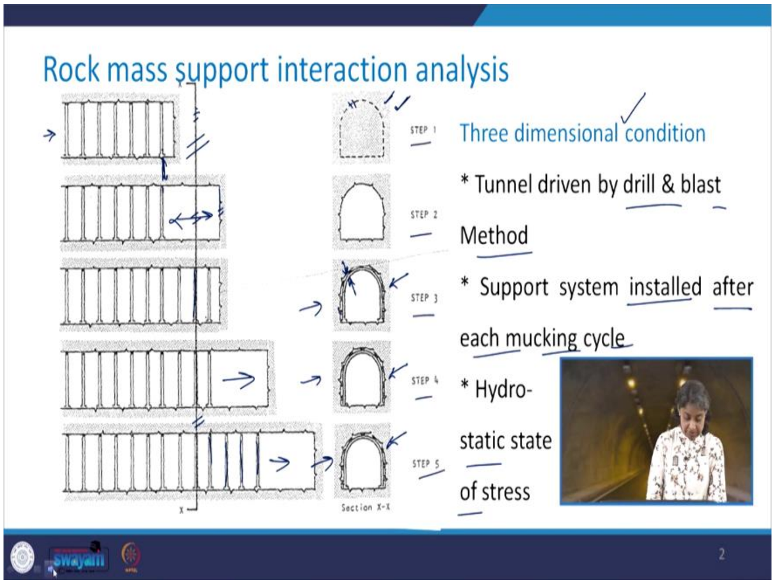
Underground Space Technology
Prof. Priti Maheshwari
Department of Civil Engineering
India Institute of Technology – Roorkee

Lecture – 42
Rock Mass Support Interaction Analysis: Ground Response and Support Reaction Curves-02

Hello everyone, in the previous class, we started our discussion on rock mass tunnel support interaction and I explained you the concept of this interaction phenomena and also, I explained you that how the behaviour of the support system and the behaviour of the excavation they are dependent on each other. And then I also explained you that what do we understand by ground response curve and support reaction curve.

Then we took a simple case of different types of rock but the 2-dimensional situation. So, today we will try to understand the same thing but with an example of a 3-dimensional situation. So, a 3-dimensional situation will look like this.

(Refer Slide Time: 01:14)



Here, I have taken an example of excavation of a tunnel and throughout the drive of the tunnel. I am keeping one section x-x constant or the common for each of these stage, and this is what is that section x-x is located at? So, we have basically five steps here, the first step where the tunnel has not yet driven up to this section x-x. So, if you just take a look from this point, that is across this section x-x.

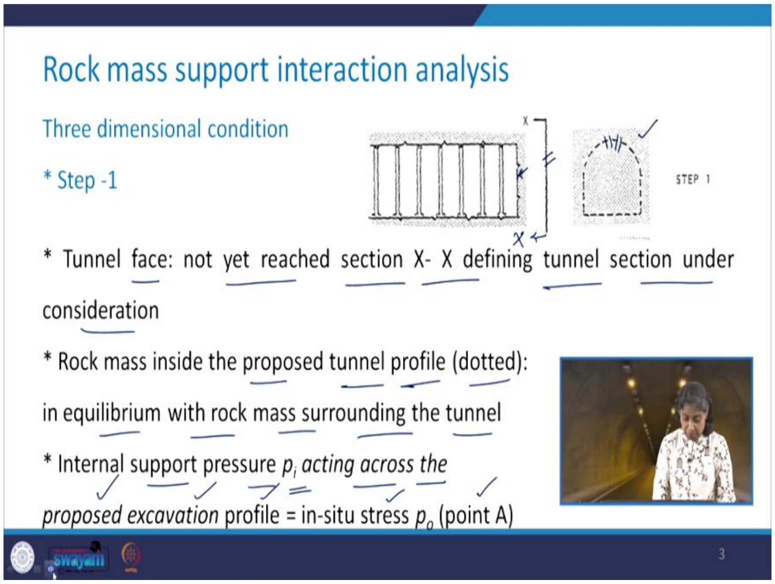
Then this will look like this particular figure, where you will not see the cross-section, but you will only see the rock mass. And that is why the tunnel cross-section has been shown in dotted lines. Then you cross-section x-x, and the driving of the tunnel is beyond the section x-x and the support systems have been installed up to the first step only that means you see that here in the first step.

The support systems were installed up to this extent, and that remains the same. So, what is done when you drive the tunnel? It is driven in some distances, and then the support system is installed up to the face. Then we further extend it again, apply the support system, install the support system, and likewise the tunnel advances. So, come to the second step, where you have advanced the tunnel beyond the section x-x but not yet provided the support system up to the complete driving of the tunnel or complete advancement of the tunnel.

Then in the third step, what you do is you? Do not excavate it further. You do not advance it further, but then before that you install the support system. So, you see the cross-section. You will see not only the excavated surface but also the support system. Then this section remains, and then we further advance the tunnel, and then we install the support system and further advance. So, likewise, we complete the tunnel and the installation of the support system with the or along the total designed length of the tunnel. So, in the step, 3, 4, and 5, you see the section x-x is the same. So therefore, in the cross-section, all of these look the same.

So basically, here what we are trying to understand is the 3-dimensional condition where tunnel is driven by drill and blast method. And support system is installed after each mucking cycle. So, you have the drill and blast method loosen the rock mass, and muck material will be there inside the cavity. You remove that muck material, install the support system. And we consider here the hydrostatic state of stress. Now, what we will do is? We will try to understand these phenomena with respect to each and every step, and then we will try to develop the ground response curve and the support reaction curve simultaneously for each of these steps.

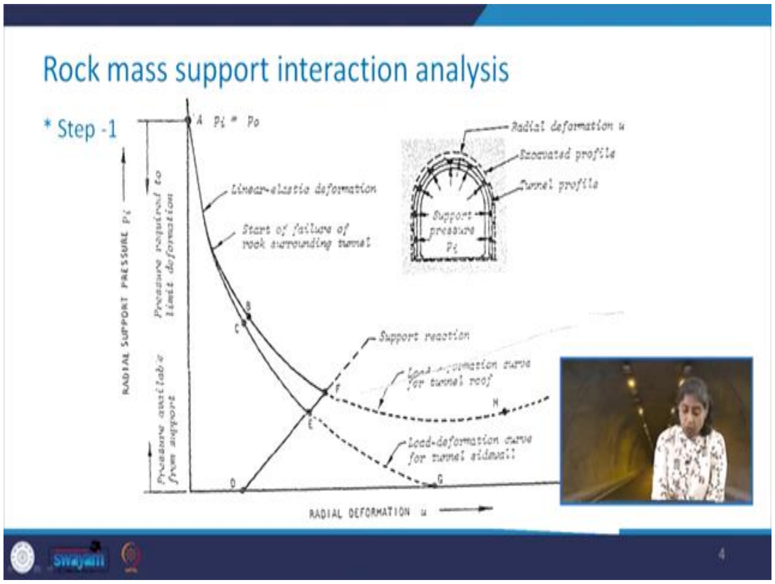
(Refer Slide Time: 05:17)



So, we take the first step where the section x-x is a head of the tunnel face here. So, you will see only the rock mass if you cut at section x-x you will see only the rock mass but of course, since the tunnel is being driven and therefore, we are showing this as a dotted line. So, basically tunnel face has not yet reached section x-x, defining the tunnel section under consideration.

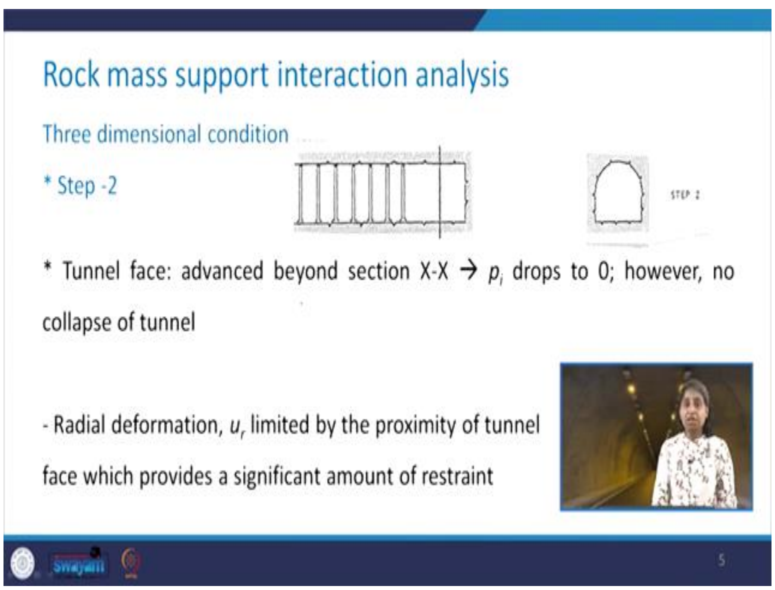
Again, note that we are advancing the tunnel, but the section x-x remains at it is location. So, the rock mass inside the proposed tunnel profile which is shown here as the dotted line. It is right now in equilibrium with the rock mass surrounding the tunnel. So, the internal support pressure p_i which is acting across the proposed excavation profile, will be equal to the in-situ stress, as we saw it in case of the 2-dimensional situation as well.

(Refer Slide Time: 06:29)



So, this has been represented by the point a here in this particular figure, where you have p_i to be equal to p_0.

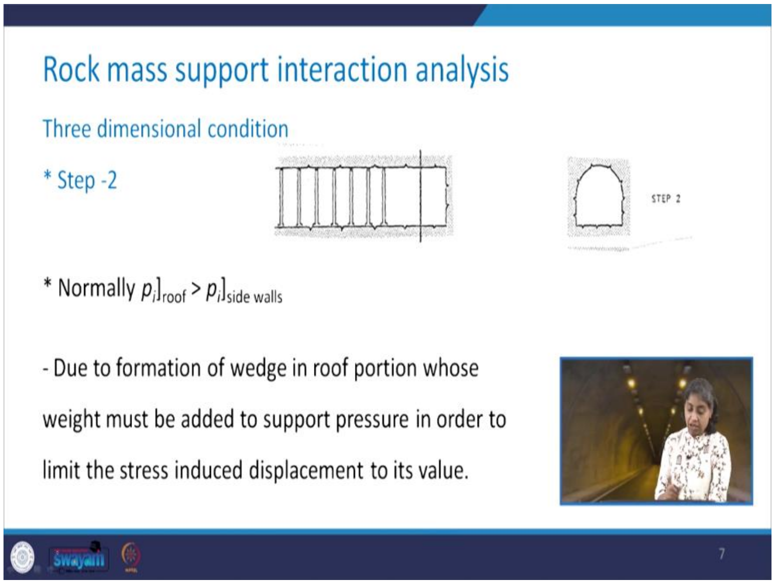
(Refer Slide Time: 06:41)



Now, what will happen? Next, we go to the step-2, where this is section x-x, and if you take a look here, you will see the excavation because now the excavation or the tunnel face has gone beyond the section x-x. So, the tunnel face advanced beyond section x-x. What will happen? This is the stress-free boundary. So, this p_i will drop to 0. However, there is no collapse of the tunnel.

And what will happen to the radial deformation which we represent by u_r? It will be limited by the proximity of tunnel face which provides the significant amount of restraint. See here this section x-x is in the proximity of this tunnel face where there is the restraint from this side surrounding rock mass.

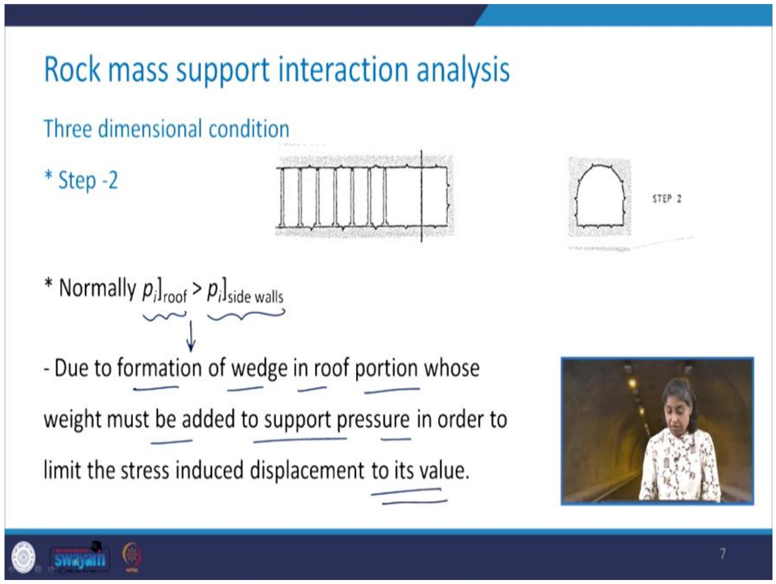
(Refer Slide Time: 07:40)



So, if this restrain is not there, there is going to be the internal support pressure p_i would be required to arrest corresponding radial deformation which is u_r at B. So, this is what is the point B. Let us take the bigger version of this figure little later. So, for the time being, just think that this point is B. Now, there are two situation roofs as well as the side wall of the tunnel.

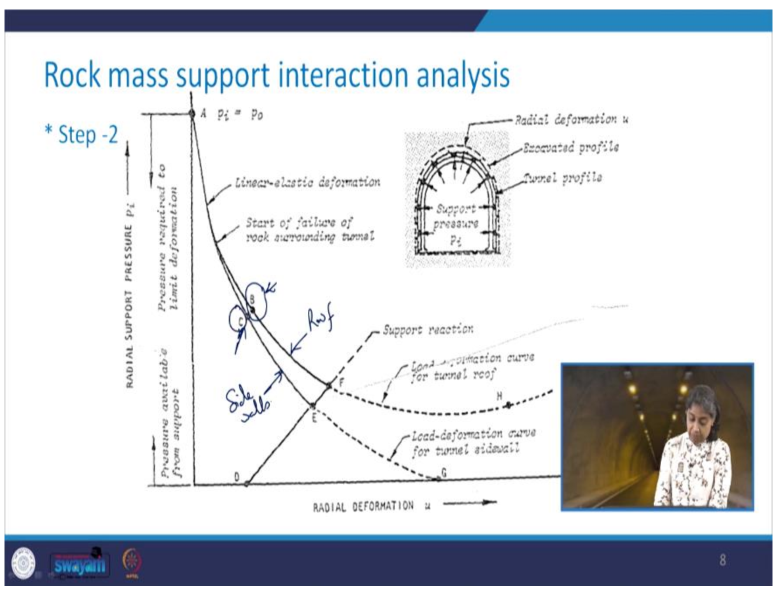
So, what will happen? Whether the roof and the side walls they are going to behave in a same manner or they will be behaving in a different manner. If they behave in a different manner, there will be one GRC for roof and another one for the side wall.

(Refer Slide Time: 08:34)



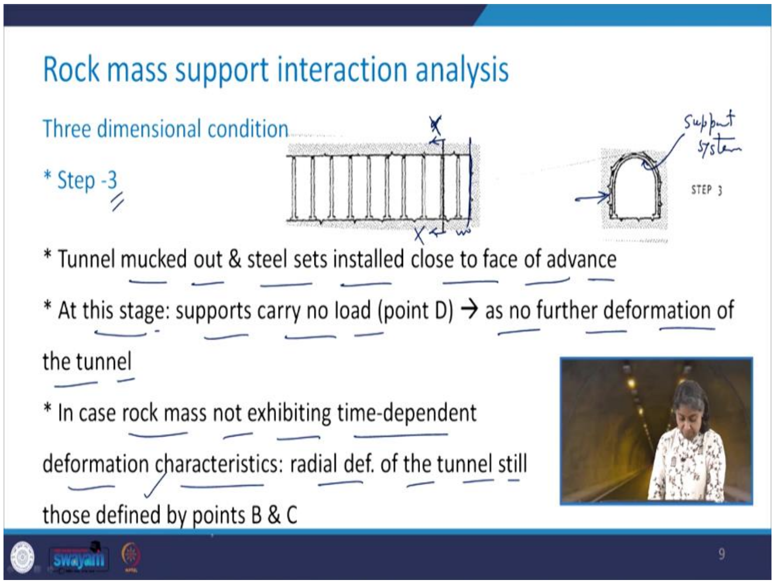
So normally, p_i roof is more than p_i of the side wall. This is why this is due to the formation of wedge in the roof portion, whose weight must be added to the support pressure to limit the stress-induced displacement to it is value.

(Refer Slide Time: 08:58)



So, therefore, we are going to have two ground response curves, one will be for the tunnel roof, and another will be for the side walls. So, corresponding to that, here is the point B that we were talking about, and this is in the roof portion, and the corresponding point in the side wall is going to be the point C here.

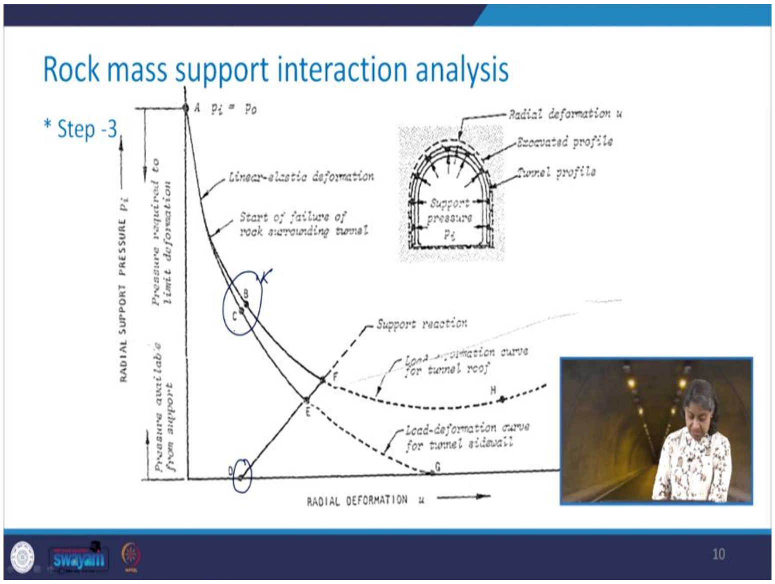
(Refer Slide Time: 09:28)



Coming to the third step, what we do? We advance the tunnel up to this in the previous step, but we did not provide the support up to section x-x, which is here. So now, what we are going to do is? We have provided in this step the support, which is beyond section x-x, so you see in the cross-section, you will see the excavated surface and also the support system. So, what is the step-3? That tunnel was marked out, and steel sets were installed close to the face of advance.

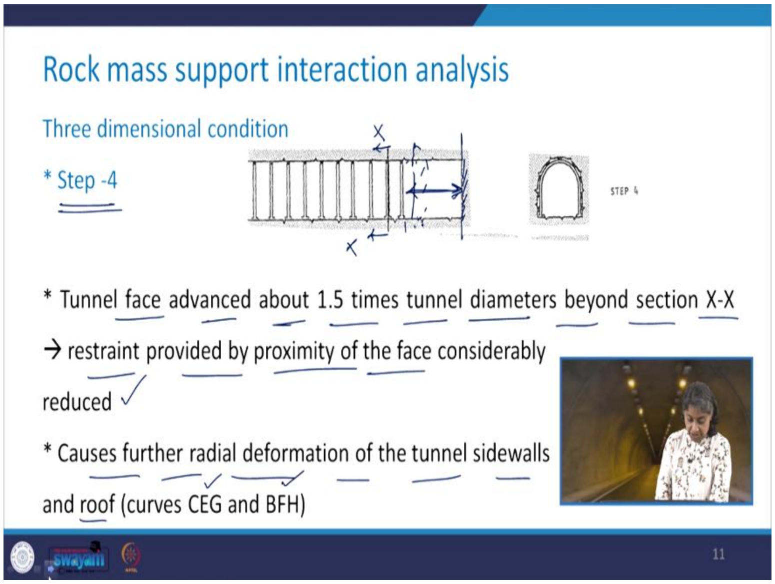
So, you see this is the face of advance, and very close to this we have provided the steel sets. So, at this stage, the supports will carry no load, as there is no further deformation of the tunnel. So, in case, if the rock mass is not exhibiting time-dependent deformation characteristic, the radial deformation of the tunnel will still be those which is defined by the points B and C.

(Refer Slide Time: 10:43)



So, you see that this is the point D because now the support system is coming into picture. So, simultaneously now, we will be starting drawing the support reaction curve along with the ground response, and since this deformation is not there right now at point D. So, basically, B and C will be the same ground response curve or the same points at ground response curve in the step-3 as well.

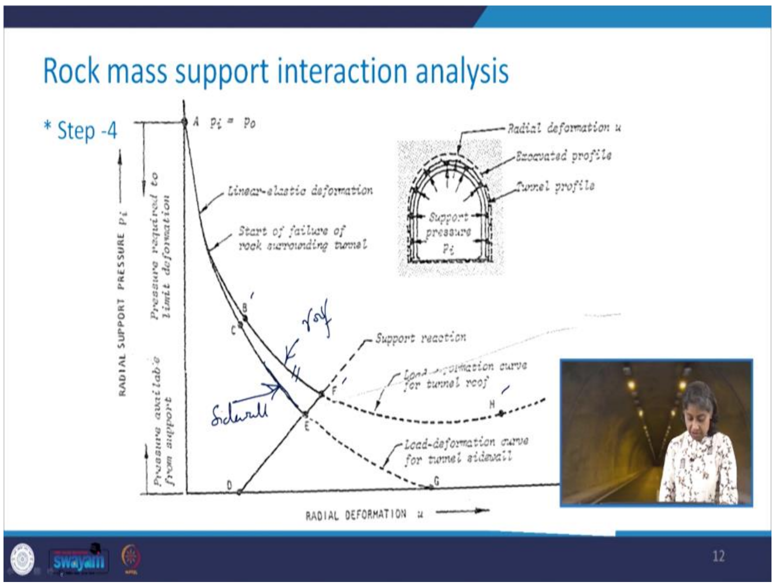
(Refer Slide Time: 00:14)



Coming to the fourth situation, what will happen now? So, we have installed the support system and further advanced the tunnel that means now tunnel face has gone beyond the section x-x, and the it is not that the support system has been installed up to the face of the tunnel. So, tunnel face advanced about 1.5 times the tunnel diameter which is beyond section x-x. So, what will happen earlier? It was up to this much.

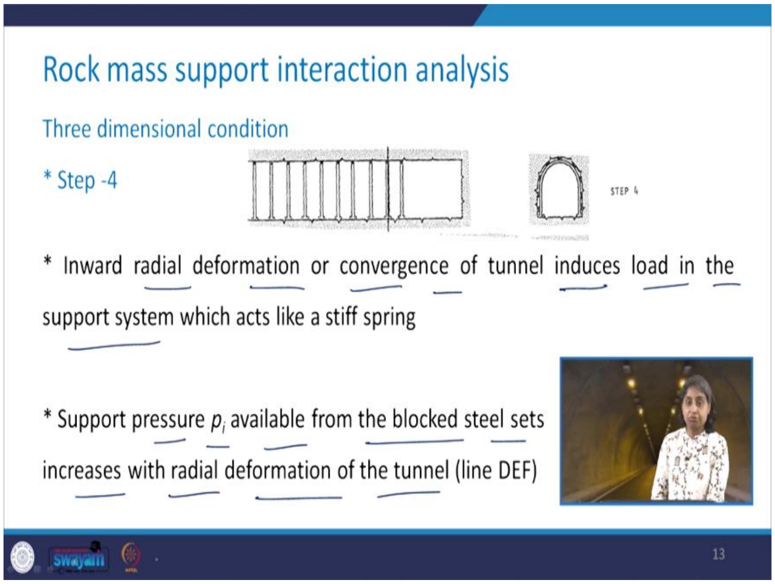
So, the constraint which was being provided by the surrounding rock mass is no more there because we have advanced it. So, the restraint which is provided by the proximity of the face is considerably reduced in this step 4, and therefore, it causes further radial deformation of the tunnel side walls as well as the roof.

(Refer Slide Time: 12:29)



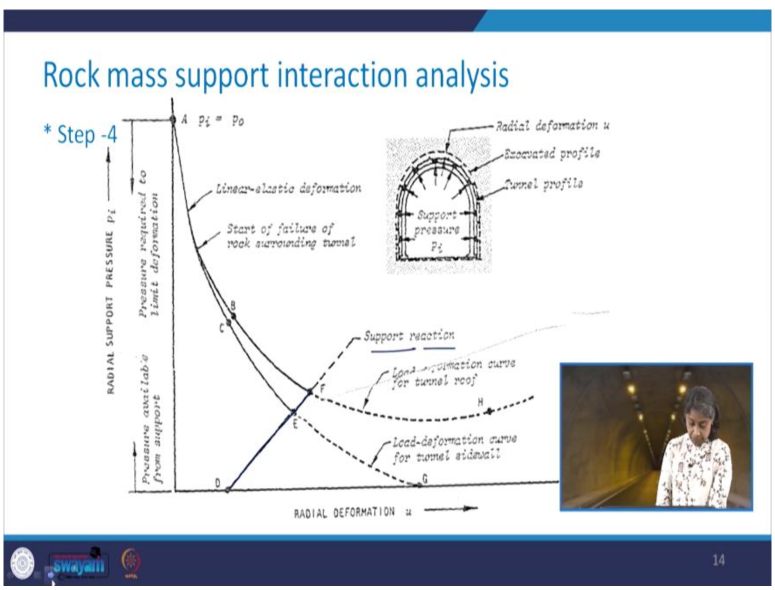
So, we have the curve CEG and BFH. In this figure that is BFH is this one BFH this is for roof, and then we have CE and then G this is for the side wall, and BFH is for roof. So, this is how the ground response curve is going to be.

(Refer Slide Time: 12:58)



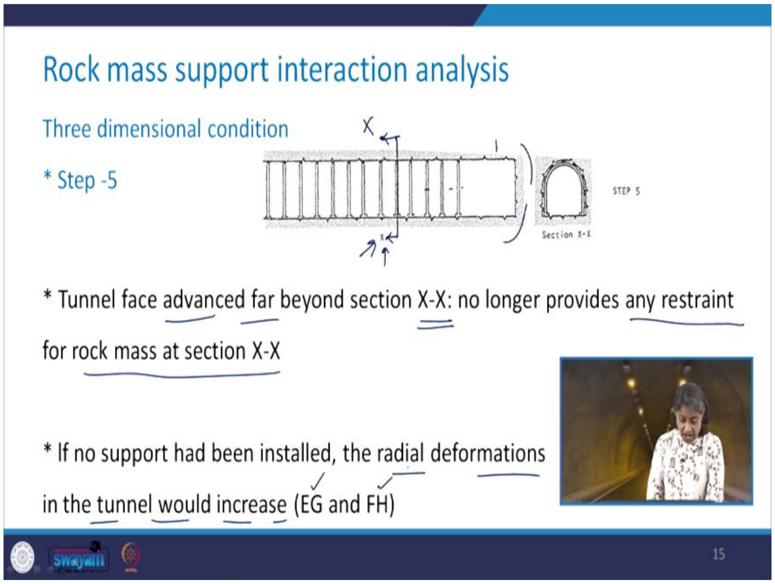
Now, what will happen? There is the inward radial deformation or convergence of the tunnel, which is there and this induces load in the support system, which acts like a stiff spring. So, as I mentioned to you earlier that the moment there is going to be the radial deformation, there is going to be the induced load in the support system. So, the support pressure p_i, which is available from the blocked steel sets it increases with the radial deformation of the tunnel.

(Refer Slide Time: 13:36)



And therefore, the support reaction curve, it now becomes this DEF line. So, this is what is your support reaction curve.

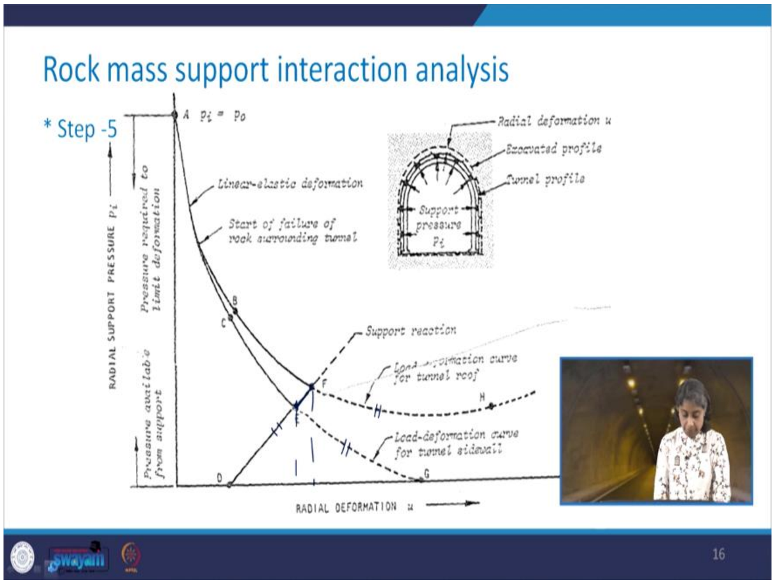
(Refer Slide Time: 13:49)



Now, we come to the step-5. So, you see how with respect to every step? We are trying to draw the ground response curve, as well as the support reaction curve. Now, we go to the next step, which is the step-5. So, what I am going to do in this case? That the tunnel face is advanced far beyond this section x-x, you see. Okay, where there is no restraint for the rock mass at x-x section. You see, there is no restraint from this rock mass because it is much far.

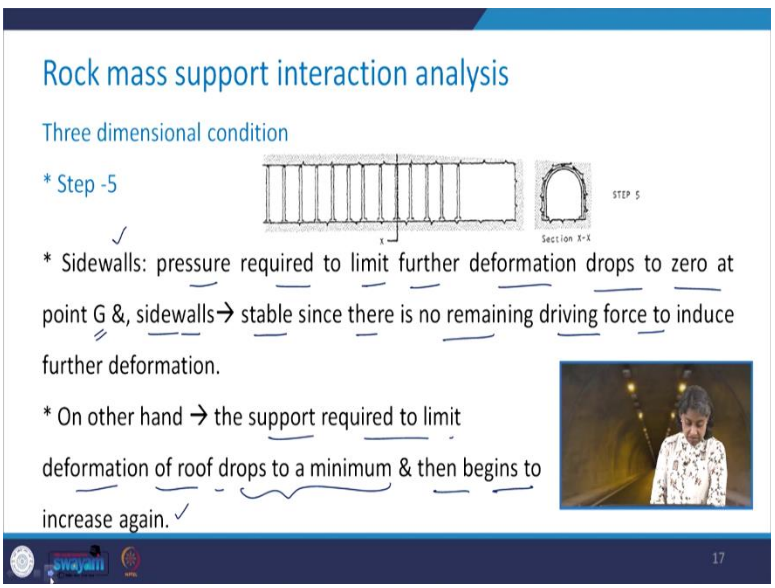
At the tunnel face has been advanced much far beyond this section x-x. So, if let us say I would not have installed any support system here, then what will happen? The radial deformations in the tunnel would increase. Right. So, therefore we have EG and FH.

(Refer Slide Time: 14:55)



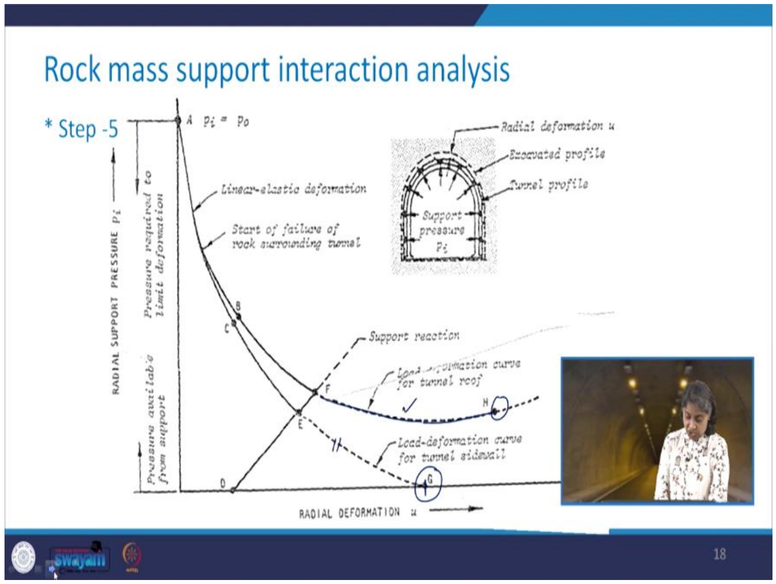
You see here this EG and FH if we do not provide any support system, but what we have done? We have already provided the support system and therefore, this deformation restricts up to this.

(Refer Slide Time: 15:13)



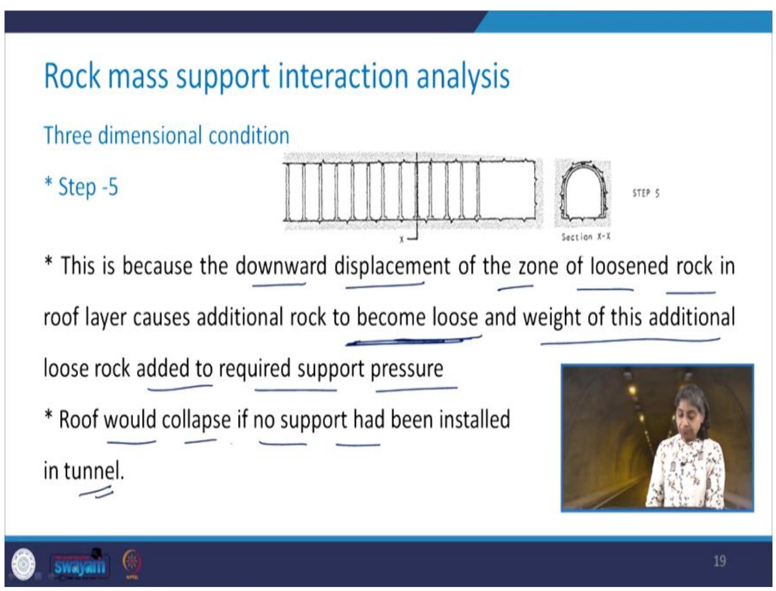
What happens in case of the side walls, the pressure which is required to limit further deformation? It drops to zero at the point G and in case of the side walls. It is stable since there is no remaining driving force to induce any further deformation.

(Refer Slide Time: 15:37)



So, you see here that this portion in the side wall this becomes equal to zero. Here, the support pressure is zero in this case. But what will happen to roof? So, on the other hand, the support which is required to limit the deformation of roof it first drops to a minimum and then again it becomes or it begins to increase. Take a look here, first it reduces little bit and then it goes and increases to this point H.

(Refer Slide Time: 16:13)

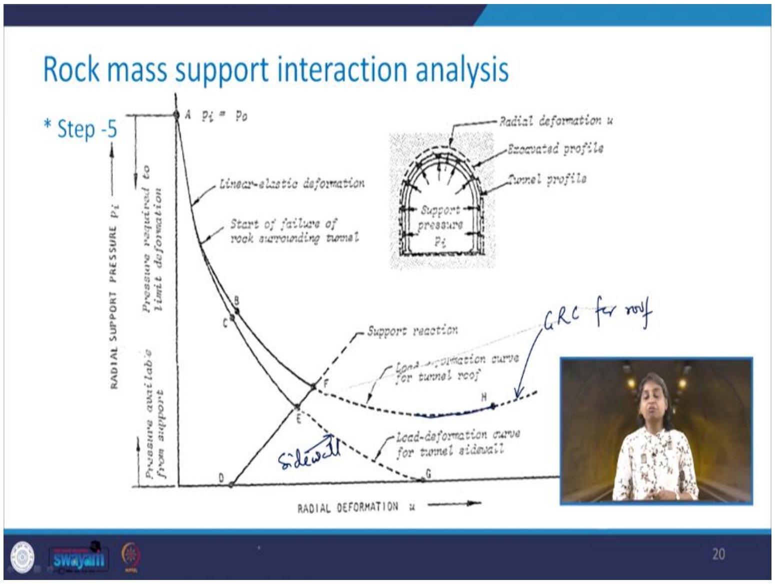


Why this type of phenomena is observed in case of the roof? The reason is that the downward displacement of the zone of the loosened rock in the roof layer, what it does? It, causes additional roof to become loose. See when we were discussing about the laminated rocks and the excavation in through those laminated rocks. There I mentioned to you immediate roof and the main roof.

And I mentioned to you that based upon the thickness and all other parameters, you can have more than one layers participating in the deformation of the roof. So, what happens? When the roof portion or the rock mass in the vicinity of the roof portion, it loosened and let us say, one block falls what happens to the rock mass? Which is immediately above that fallen rock mass that also becomes in the loose state. So, what happens because of that?

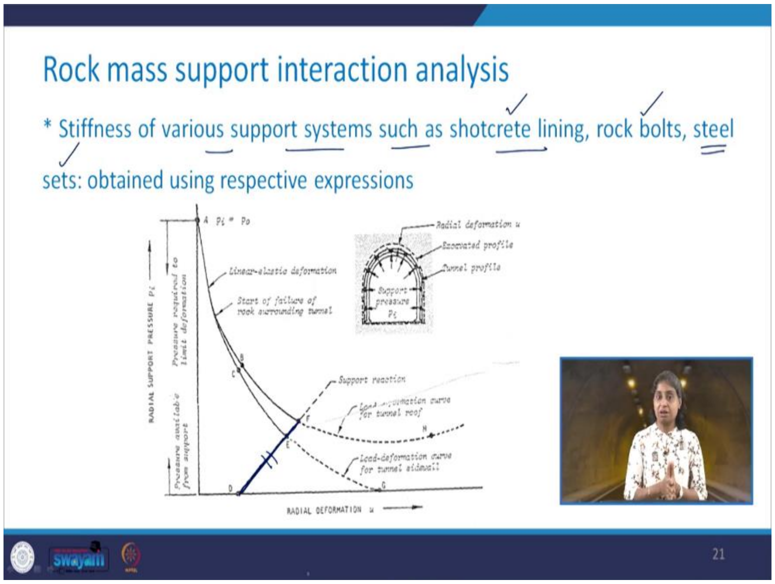
So, the additional rocks which become loose it is weight, will be added to the required support pressure. So, the roof would collapse if you do not provide the support system earlier in the tunnel.

(Refer Slide Time: 17:50)



So, therefore, you see such rise in the GRC for the roof. This is what is GRC ground response curve for roof, and this is for the side wall.

(Refer Slide Time: 18:09)



So, this is how with reference to a 3-dimensional situation, you can visualize that how the support reaction curve and ground response curve one can develop. Now, coming to the stiffness of the various support systems which can be shotcrete lining, rock bolts, steel sets. These can be obtained using respective expressions. This we will learn when we discuss about the Ladani's rock mass support interaction analysis.

So, we have various expressions. So, what will be the slope of this support reaction curve? It will depend upon whether you have adopted the support system as the shotcrete lining or rock bolt or the steel sets. So, based upon that you can find out that what will be the stiffness of this system support system. And accordingly, you can draw the line DEF.

So, this is how in the case of the 3-dimensional situation, we can develop ground response curve, as well as the support reaction curve. The ground response curve for the roof and the side walls is going to be different, and we saw that why they have the typical shape for roof and typical shape for the side walls.

As far as the support systems are concerned, their stiffness can be defined by different expressions, which we will learn in a short while. And based upon what type of the support system that is being installed? You can have the slope of the support reaction curve. So, we will continue our discussion on this rock mass tunnel support interaction analysis in the next class. Thank you very much.