Underground Space Technology
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Module No # 02
Lecture No # 10
Tunneling: Good Conditions

Hello everyone, in the previous class, we saw that what all are the various types of underground excavations. And we also started our discussion on ground conditions. If you remember, I mentioned to you about the tunnel boring machine. So today, I will show you some of the pictures related to tunnel boring machine, and then we will continue our discussion on ground conditions.

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So here you see that these are the 2 pictures which show various views of tunnel boring machine. So here you can see it is the front face, and you can see that the shield is there and see even if you have the buildings on this side, an underground excavation can be carried out without any difficulty with the help of this tunnel boring machine. So, it is not only the machine; it is a complete technology that is there, and you can see that it is huge. So, in most of the projects these days, they are carried out by tunnel boring machine.

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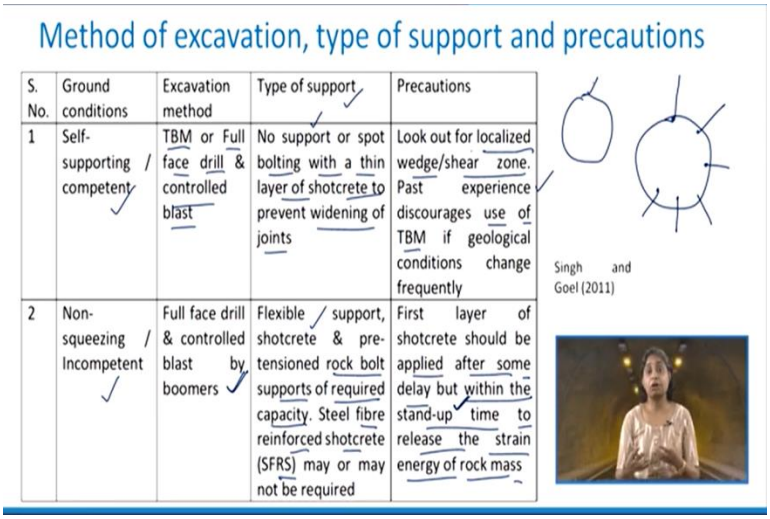

Coming to the various methods of excavation, then type of support, and precautions corresponding to every ground conditions. So, these ground conditions and the typical behaviour of the rock mass corresponding to a particular type of ground condition we saw in the previous class. So, today we will see what are the most suitable excavation method and the type of support corresponding to any particular ground condition?

And what all are the precautions that one must adopt while going for the tunnelling through these kind of ground conditions? If you remember, the first type of ground condition was self-supporting and competent. So the excavation method, in this case, is either the tunnel boring machine or full face drill and controlled blast. So right now, you just read this because later in this course, I will tell you that how this drill and blast method works and what are the various steps which are involved?

So in case of the type of the support in the previous class, also I mentioned that in case of the self-supporting or competent type of ground condition. Basically, no support is needed, or sometimes spot bolting with a thin layer of shotcrete is to be applied to prevent the widening of joints which may be there because of the excavation process. One need to exercise these precautions as has been listed here that one has to look out for the localized wedge or shear zones. The past experience discourages use of TBM if the geological conditions they change frequently.

The second type of ground condition includes non-squeezing or incompetent ground condition. In this case, it is the full-face drill and controlled blast by boomers they are recommended. The type of support which is most suitable include flexible support, shotcrete, and pre-tensioned rock bolt supports of required capacity. SFRS that is steel fiber reinforced shotcrete may or may not be required.

So, you will learn about these support systems also later in this course, but for the time being, I will just tell you that if, let us say this is the excavated surface of the rock mass, then we spray the layer of concrete or shotcrete that is what we call as the shotcrete lining, and also, we provide the rock bolts into the rock mass like this. So basically, it stitches the loosened portion of the rock mass, which may have happened because of the excavation methodology.

So, the first layer of shotcrete it should be applied after some delay but within the stand-up time to release the strain energy of rock mass. Now, there is another term which we have not discussed till now. It is the stand-up time says you have excavated the ground. So, the stand-up time is the time between the excavation and the support installation such that this excavated portion can stand on its own.

So, let us say if the ground condition is self-supporting or competent, you will have very large stand-up time that means that the rock mass, even after excavation can stand on its own up to that much of the time; this time is called as the stand-up time.

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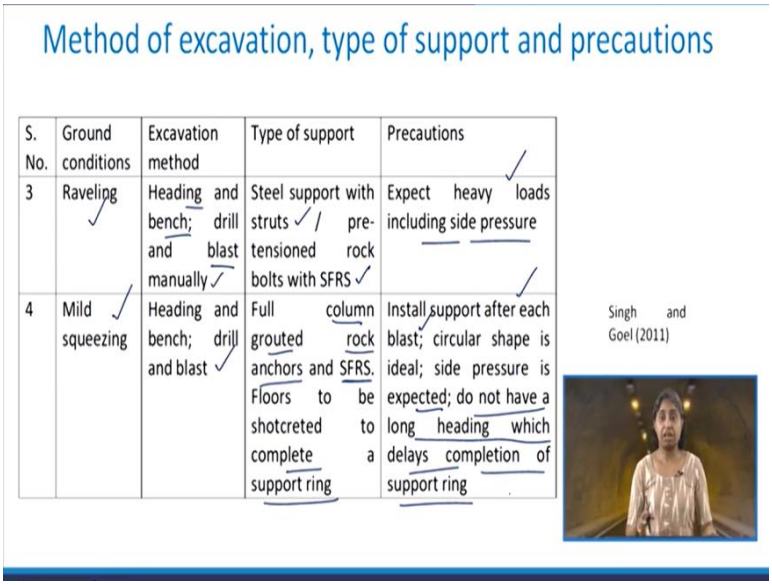

Third type of ground condition is raveling, and the preferred excavation method is heading and benching method and drill and blast manually. In this case, steel support with struts or pre-tensioned rock bolts with SFRS they are provided. In this case, we can expect heavy loads including side pressure because it is the raveling condition, and I told you that what happens in raveling ground condition. The moment you excavate there can be some fall out of the wedges from the crown or the side walls of the tunnel.

Then, the fourth ground condition is mild squeezing, and the excavation method is heading and benching and drill and blast method which is recommended. In this case, full column

grouted rock anchors, and SFRS is preferred. In this case, floors are to be shotcreted, or complete support ring should be provided. Now, we need to install these support after each blast. In this case, the shape of the tunnel should be the circular shape as it provides the most ideal condition.

The side pressures are also expected, so we should not have a long heading which delays the completion of the support ring. So simultaneously, after each blast cycle, we should keep installing the support systems.

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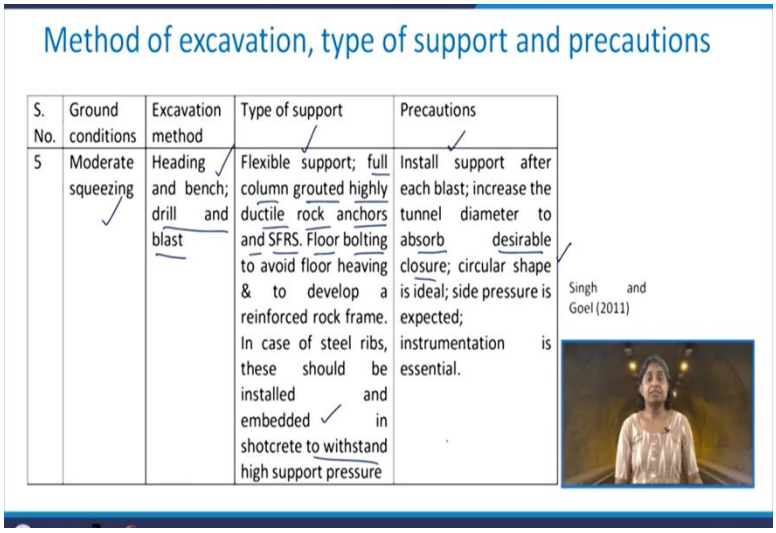

Coming to the next category, which is the moderate squeezing, the excavation method which is most preferred in this case is heading and bench method and drill and blast method. One can go for flexible support full-column grouted highly ductile rock anchors and SFRS. One can adopt floor bolting to avoid floor heaving and to develop the reinforced rock frame. Now in case, if it is designed that the steel ribs are to be provided so these should be installed and embedded in shotcrete to with stand high support pressure.

The precautions which are to be exercised is that we need to install the support after each blast increase the tunnel diameter to absorb desirable closure. Then, in this case, also the circular shape of the tunnel is the ideal, and the side pressure is expected, and instrumentation is essential during and after the construction of the tunnel.

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Method of excavation, type of support and precautions

S. No.	Ground conditions	Excavation method	Type of support	Precautions
6	High squeezing	Heading and bench in small tunnels & multiple drift method in large tunnels; use forepoling if stand-up time is low	Very flexible support; full column grouted highly ductile rock anchors & slotted SFRS; yielding steel ribs with struts when shotcrete fails repeatedly; steel ribs may be used to supplement shotcrete to withstand high support pressure; close ring by erecting invert support; encase steel ribs in shotcrete, floor bolting to avoid floor heaving; sometimes steel ribs with loose backfill are also used to release the strain energy in a controlled manner (tunnel closure more than 4% shall not be permitted)	Increase the tunnel diameter to absorb desirable closure; provide invert support as early as possible to mobilize full support capacity; long-term instrumentation is essential; circular shape is ideal

Coming to the sixth ground condition that is high squeezing condition so the excavation method that is recommended is to go for heading and benching in small tunnels and multiple drift method in large tunnels. So, one can use forepoling if the stand-up time is very low, so very flexible support is needed. And this include full-column grouted, highly ductile rock anchors and slotted SFRS then, yielding steel ribs with struts can also be adopted.

When the shotcrete fails repeatedly, these steel ribs may be used to supplement the shotcrete to withstand high support pressure, and some of the other conditions they are all mentioned here. Now the precaution that one should keep in mind is to increase the tunnel diameter to absorb the desirable closure. So what is done is? The excavated diameter is more than what is needed; what is the final diameter of the tunnel?

So what happens? Because of this squeezing phenomenon, there is the convergence of the tunnel, and therefore if you have the excavated tunnel diameter on the higher side, then it will absorb this desirable closure. So, we need to provide the inward support as early as possible to mobilize full support capacity. In this case, long-term instrumentation is essential, and the shape of the tunnel, which is ideal is the circular shape.

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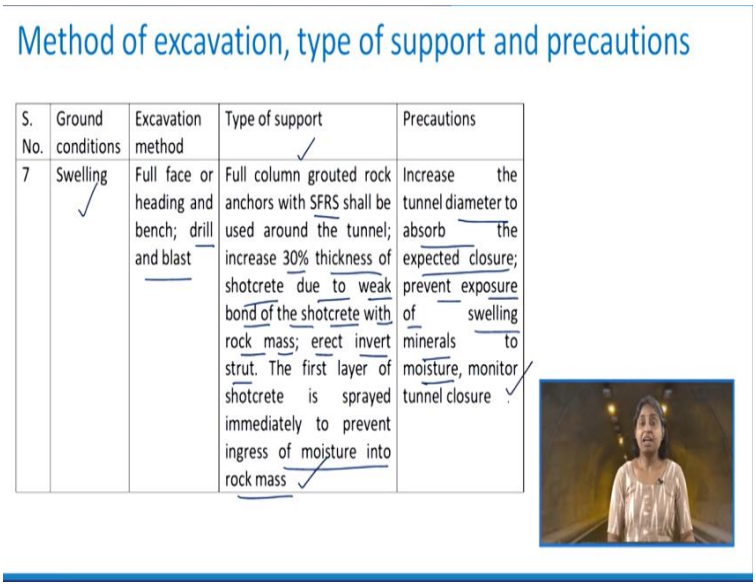

Coming to the next ground condition which is swelling. The recommended excavation method is full face or heading and bench and drill and blast method. Again, in this case, you need to use this full-column grouted rock anchors with SFRS, and these shall be used all around the tunnel. So increasing 30% thickness of the shotcrete, due to weak bond of shotcrete with rock mass that is recommended.

One needs to erect the invert struts, then the first layer of the shotcrete is sprayed immediately to preventing rest of the moisture into the rock mass; why? Because in case of the swelling condition, once the rock mass is exposed to the water, it expands in volume, and that is not desirable. So immediately upon excavation, the first layer of shotcrete is sprayed to prevent the ingress of moisture into the rock mass.

Now the precaution that one must keep in mind is to increase the tunnel diameter to absorb the expected closure. Then prevent the exposure of swelling minerals to moisture, and one must monitor that what is the level of tunnel closure?

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Method of excavation, type of support and precautions

S. No.	Ground conditions	Excavation method	Type of support	Precautions
8	Running and flowing	Multiple drift with forepoles; grouting of the ground is essential; shield tunneling may be used in soil conditions	Full column grouted rock anchors and SFRS; concrete lining up to face; steel liner in exceptional cases with shield tunneling	Progress is very slow. Trained crew should be deployed
9	Rock Burst	Full face drill & blast	Fibre reinforced shotcrete with full column resin anchors immediately after excavation	Micro-seismic monitoring is essential

Next ground condition is running and flowing, so if you recall, in the previous class, I kept it as a 2 different ground condition which was running as well as flowing. But here, what I have clubbed these 2 under one category because of the similar treatment which is to be given if the excavation is made through such ground conditions. So, the recommended excavation method is multiple drift with 4 poles grouting of the ground is essential in this case and shield tunneling may be used in the soil conditions.

Then full-column grouted rock anchors, and SFRS are the preferred type of the support. Concrete lining up to the face steel liner in exceptional cases with shield tunneling is to be opted for. In this case, the progress of the advance of the tunnel is extremely slow, and the trained crew should be deployed so as to have the proper support installation and the tunneling procedure.

The next ground condition includes rock burst, and in this case, full face drill and blast method should be adopted as an excavation method. The support that is needed is fiber-reinforced shotcrete with full column raisin anchors, which are to be installed immediately after excavation. In this case, microseismic monitoring is essential: mentioned to you that under such type of ground condition the behavior are violent and sudden. So, one need to be careful as far as the monitoring is concerned.

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General categories of ground behavior types

S. No.	Behavior type	Description of potential failure modes/mechanisms during excavation of the unsupported rock mass
1	Stable	Stable rock mass with the potential of small local gravity induced falling or sliding of blocks
2	Discontinuity controlled block failure	Deep reaching, discontinuity controlled; gravity-induced falling and sliding of blocks; occasional local shear failure
3	Shallow stress-induced failure	Shallow stress-induced brittle and shear failures in combination with discontinuity and gravity controlled failure of the rock mass

Singh and Goel (2011)

Coming to the general categories of ground behavior type, so here we are going to discuss about some general aspects related to type of the behavior of the ground and what can be the potential failure mode or the mechanism during the excavation of the unsupported rock mass. So here is a table; the second column shows the type of the behavior, and the last column gives us the idea about the potential failure modes.

So, the first one includes the stable type of behavior; this has the stable rock mass with the potential of only small local gravity-induced falling or sliding of blocks. Now when it is discontinuity-controlled block failure, it is deep reaching and discontinuity control the gravity-induced falling and sliding of blocks can be observed, and then occasional local shear failure can also take place.

Now in case of shallow stress-induced failure, it can be brittle, and shear failures in combination with the discontinuity and also the gravity-controlled failure of the rock mass.

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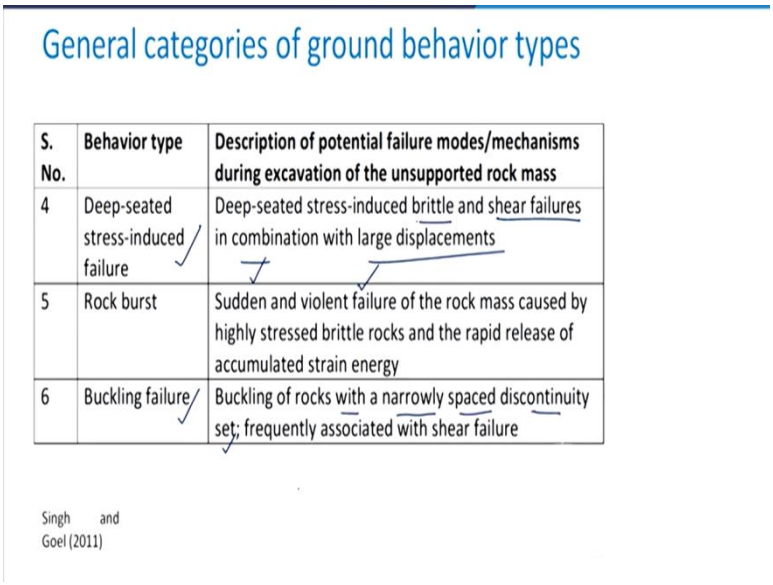

So these are the first 3 behavior type, coming to the fourth one, which is deep-seated stress-induced failure. So here, it includes brittle and shear failures in combination with the large displacement. So takes place in case if the behavior is deep-seated stress-induced failure. In case of the rock burst, as I already mentioned to you that there is going to be sudden and violent failure of the rock mass.

And this will be caused by highly stressed brittle rocks, and there is going to be the rapid release of accumulated strain energy and therefore, you observe sudden and violent failure of the rock mass. Coming to the next behavior type, which is the buckling failure so; in this case, the buckling of rocks with a narrowly spaced discontinuity set and these are frequently associated with shear failure.

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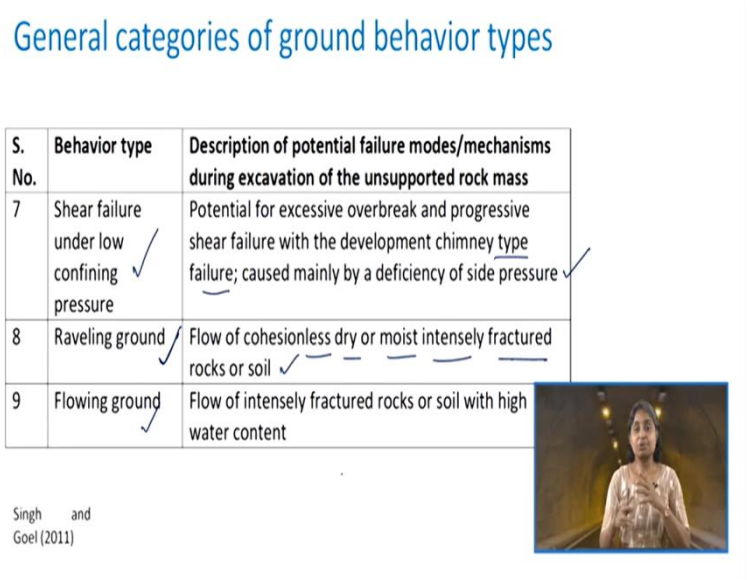

Then we have the next category as the shear failure under low confining pressure. So, the potential failure mode include here that there is going to be the excessive outbreak and progressive shear failure with the development of chimney-type failure. And these are caused mainly by a deficiency of the side pressure. Then the next condition is raveling ground; there is going to be the flow of cohesionless dry or moist intensely fractured rocks or soil.

If you have the raveling ground type of behavior in case if it is flowing ground then there is going to be the flow of intensely fractured rock or soil which is mixed with high water. So, there is going to be the mixture of these highly fractured rocks or soil and the water under flowing ground behavior type.

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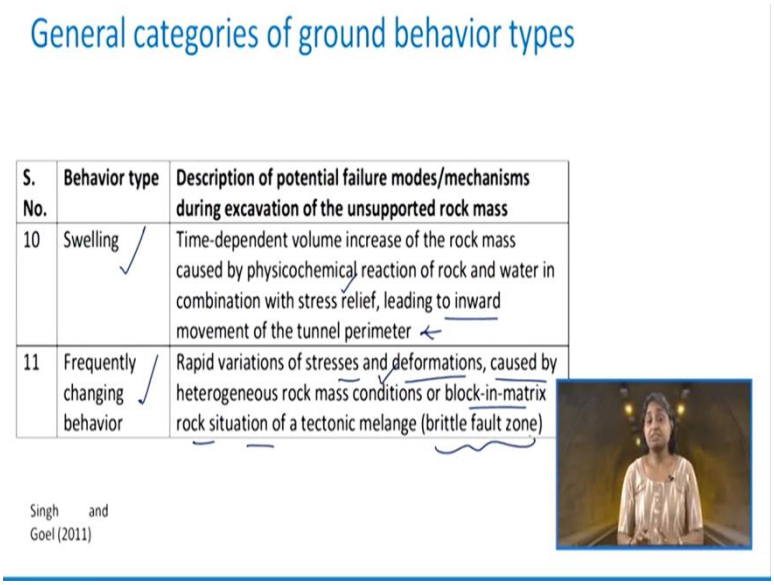

Then, we have the next category, which is the swelling type of behavior. In this case, we have the time-dependent volume increase which is caused by the physiochemical reaction of rock and the water in combination with the stress relief. So this leads to inward movement of the tunnel perimeter. So basically, swelling is associated with the exposure of rock mass with water.

Now, another failure type can be that let us say, it is frequently changing its behavior. The causes can be that there is a rapid variations of stresses and deformation. These are caused by the heterogeneous rock mass condition or block in matrix rock situation of a tectonic or brittle fault zone. So in such case, one needs to be very careful because the behavior of the ground is changing frequently.

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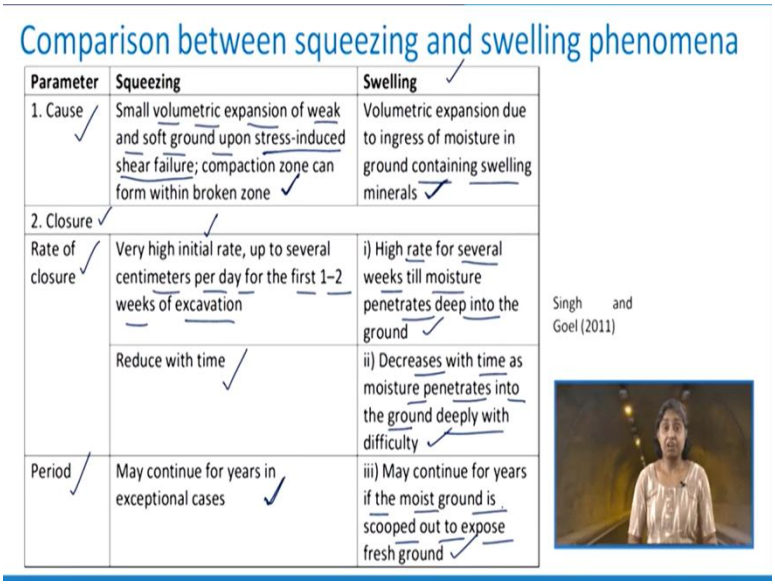

So, we have been discussing about the squeezing and the swelling ground condition, although I mentioned to you the difference between these 2. And we saw that when there is a swelling ground condition, it is mostly associated with the expansion of the rock mass in volume under the influence or the exposure of water. But then there are few other parameters based upon which you can differentiate between squeezing and the swelling ground condition.

So, we are going to discuss some of these, and this will also make very clear to you that the difference between squeezing and the swelling ground condition. So the first parameter is the cause, so in case of the squeezing ground condition, it is caused by the small volumetric expansion of weak and the soft ground upon stress-induced shear failure. Remember, it is stress-induced shear failure, so the compaction zone can form within the broken zone.

However, in case of the swelling ground condition, this volumetric expansion is due to ingress of moisture in ground which contains swelling minerals. So remember in case of squeezing ground condition, it is stress-induced shear failure, and in case of the swelling ground condition, it is because of the ingress of water in the ground which contains the swelling minerals.

Second parameter is the closure, so when we talk about the closure, it is the rate of closure and period; so first we take up that what is the rate of closure. So in case of the squeezing ground condition, it has very high initial rate up to several centimetres per day for the first 1 to 2 weeks of the excavation. However, in case of the swelling ground condition, there is high rate for several week still moisture penetrates deep into the ground.

So in case of the squeezing rock, it is high rate is up to 1 to 2 weeks of excavation, but in case of the swelling ground condition, it takes several weeks. Now this rate of closure it reduces with time in case of the squeezing ground condition. But in case of the swelling, it reduces with time as the moisture penetrates into the ground deeply with difficulty that is the main difference.

Coming to the parameter called period, these may continue for years in exceptional cases, and in case of the swelling ground condition, these may continue for years if the moist ground is scooped out to expose to fresh ground.

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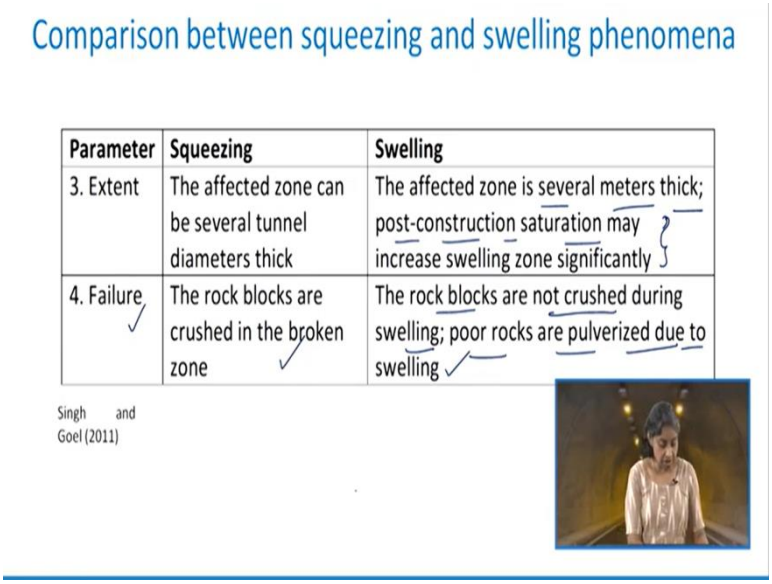

Coming to the extent of squeezing and swelling in the rock mass so for the squeezing rock mass the affected zone can be several tunnel diameters thick. Let us say that if the diameter of the tunnel is, say 10 meters, so it can be 20-30 like that, so it can be several tunnel diameter thick the extent can be that high. But in case of the swelling type of ground condition, the affected zone is several meters thick. So, in this case, what happens is post-construction saturation that may increase swelling zone significantly.

But before that, see the swelling behavior is coming into picture if there is a presence of those types of minerals which show such type of characteristics in the presence of water. And therefore here, post-construction saturation may increase the swelling zone significantly. The failure the rock blocks are crushed in the broken zone as far as the squeezing ground condition is concerned.

However, in case of the swelling ground condition, these rock blocks they are not crushed during swelling, but poor rocks are pulverized due to swelling. So there is a difference in the mode of failure as well for squeezing ground condition and the swelling ground condition. So in today's lecture, we learnt about the ground condition corresponding excavation method and the support system. And also that what all are the precaution that one should take while going for the tunneling under each of those ground conditions?

Then we also discussed about the difference between squeezing and swelling type of ground conditions. So in the next class, we will learn about the planning and exploration of the underground excavations. Thank you very much.