Rock Engineering
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Lecture-36
Tunneling: Ground Conditions

Hello everyone. In the previous class, we started our discussion on tunnelling, I mentioned to you, various types of underground excavations and also introduced you, various ground conditions. Today, we will learn about the method of excavation, support system and the mode of failure which occurs in those ground conditions. But, before that, I promised you that I will show you the tunnel boring machine with the help of few pictures. So, first let us have a look that how this tunnel boring machine looks like.

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So, here are the views, this is the front portion of this TBM which is this portion. So, you can see that it is a very long assembly, it has various components and for the scope of this course, it is not there. So, what I mean to say is that when you hear about this tunnel boring machine this picture should come in your mind. So, what happens is there is shield. It helps in advancing the tunnel in its direction of advance. So, this is what when I say tunnel boring machine, you should immediately have these pictures in mind.

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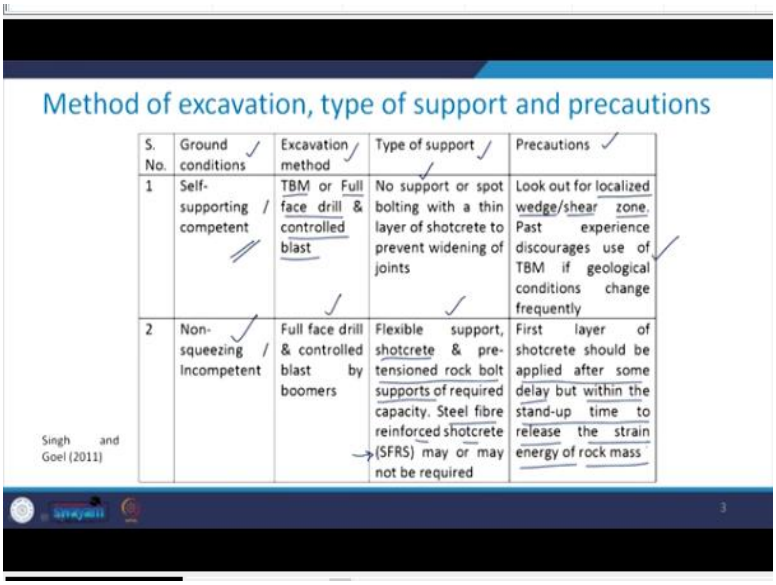

Coming to various method of excavation, type of support and precaution to be taken during the excavation for different ground conditions. So, the second column deals with the ground conditions followed by the excavation method, the type of support and the precautions to be adopted. So, we discussed in the previous class the first ground condition was self-supporting or competent ground.

So, the excavation method in this case can be TBM, which is tunnel boring machine or full-face drill and controlled blast. No support is required or spot bolting with a thin layer of shotcrete to prevent widening of the joints can be installed. As far as different types of the support systems are concerned. Once we finish our discussion on the analysis of the tunnels, then we will learn about the support systems and about their design also.

So, there we will have the detailed discussion related to these, for the time being please understand that these are the type of the support which would be applicable corresponding to each of the ground conditions. In this case one needs to be careful about the localized wedge or shear zones. The past experience discourages the use of TBM if geological conditions change frequently.

Coming to the next ground condition, which is the non-squeezing or incompetent ground. In this case, full face drill and controlled blast by boomers is what is recommended, one needs to have the flexible support, shotcrete and pre-tensioned rock bolts supports of the required capacity. Now how to determine the required capacity of the rock bolts etcetera we will learn.

Steel fiber reinforced shotcrete which is in short called as SFRS may or may not be required in this case.

We need to be careful that first layer of shotcrete should be applied after some delay but within the standard time to release the strain energy of the rock mass. So, the moment this excavation takes place we need to wait for some time so that this strain energy of the rock mass is released, but we should not wait a long and provide the support system within the stand-up time.

So, this is what is the precaution that one needs to keep in mind in case if the excavation is taking place through non squeezing or incompetent ground.

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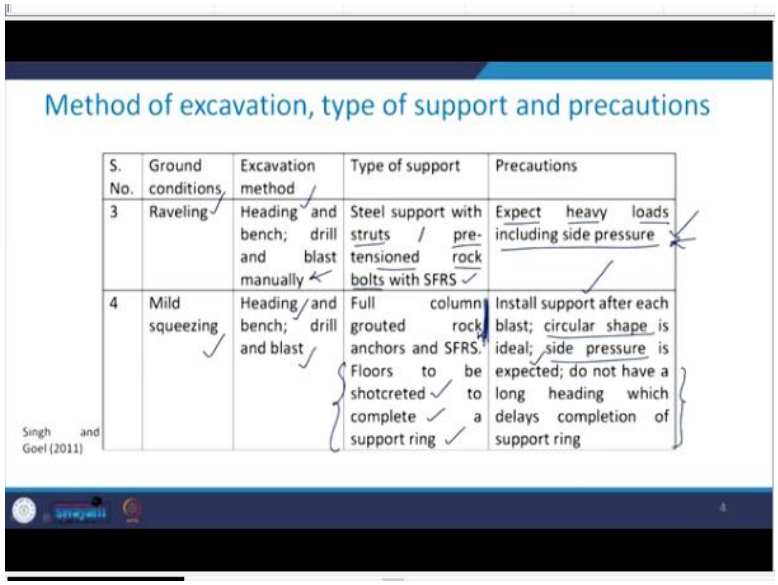

The next condition is the raveling, in this case one needs to go for heading and bench method and drill and blast manually, steel support with struts or pre-tensioned rock bolts with SFRS are recommended. In this case we expect heavy loads including the side pressures. So, we have to design the support system keeping this in mind. Next one is the mind squeezing and the excavation method which is recommended is heading and bench, drill and blast.

Full column grouted rock anchors and SFRS are recommended as the type of support. Floors to be shot created to complete a support ring along with this reinforced system this additional thing should be provided. In this case we need to install the support after each blast. Let us say the tunnel has to run for say few kilometres, it is not that we have the blast all along the length of the tunnel in one go, we do it in stage vice manner.

So, let us say that you have the blast in the first stage. So, first you provide the support in that state before you go for the next round of the blast. In this case the circular shape of the tunnel is ideal, side pressure is what is expected, we do not have a long heading which delays the completion of the support ring.

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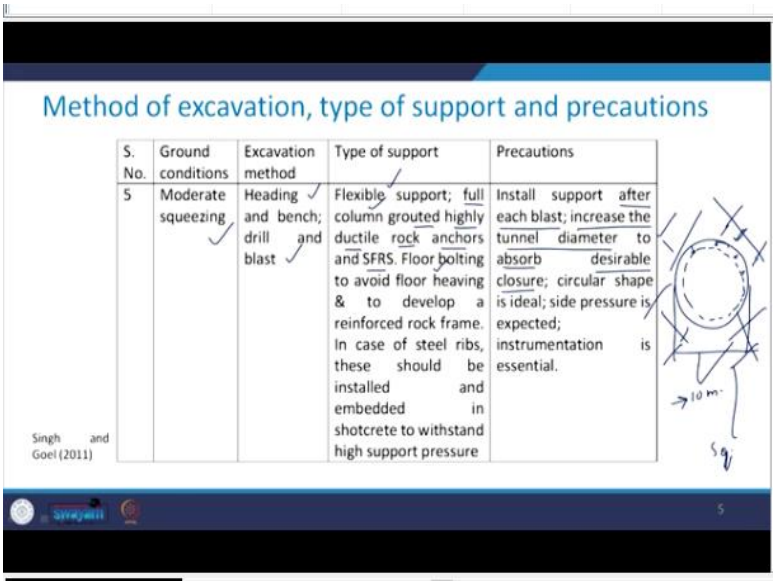

Next one is the moderate squeezing and the excavation method which is recommended is heading in benching method and drill and blast. Again, in this case one needs to go for flexible support. Full column grouted highly ductile rock anchors and SFRS. Floor bolting should be provided in order to avoid floor heaving and to develop a reinforced rock frame. In case of steel ribs these should be installed and embedded in shotcrete to withstand the high support pressure.

What are the precautions that one needs to keep in mind, is that again in this case we need to install the support after each blast, increase the tunnel diameter to absorbed desirable closure. As I explained you in the previous class that when you have the squeezing ground condition and say the tunnel diameter is 10m. So, what will happen? See here in this figure this is what is your final diameter of the tunnel?

Say this is 10 meters for instance, now if it is the squeezing ground condition say all around this tunnel it is the squeezing ground condition. Now what will happen because of this? This rock will squeeze inside the tunnel. So, it is diameter will be reduced because of these squeezing phenomena and no more be what we want it to be as 10 meters. Therefore, in this case we need to increase the tunnel diameter to absorb this desirable closure. Circular shape is ideal, side pressure is expected and instrumentation is essential in this case.

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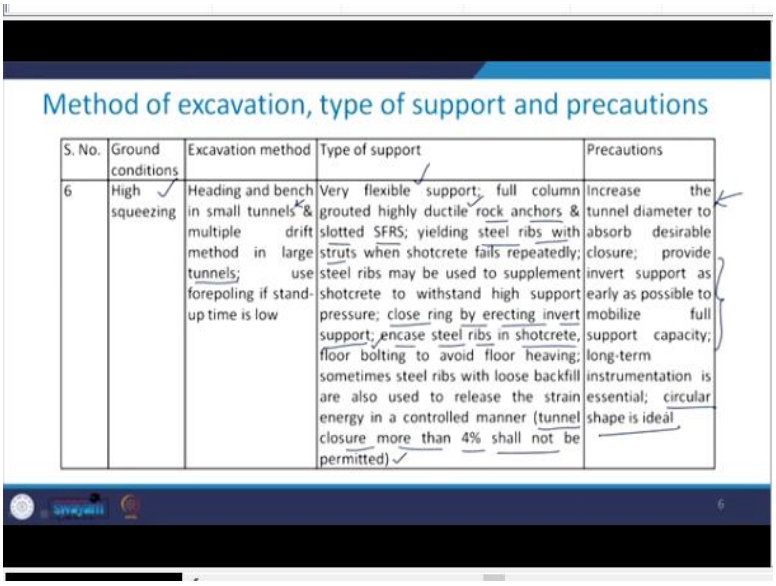

Coming to the next ground condition which is the high squeezing condition, heading and bench in small tunnels and multiple drift method in large tunnels, use fore-poling if standard time is low. Now the type of support you can see that it is a long list. Let us see slowly what does this mean? In this case one needs to go for very flexible support system. It can be full column grouted highly ductile rock anchors and slotted SFRS.

Yielding steel ribs with struts when the shotcrete fails repeatedly, that also can be one of the options. Steel ribs may be used to supplement the shotcrete in order to withstand the high support pressure. Then close rings by erecting the invert support also can be provided, one can encase the steel ribs in shotcrete, then floor bolting can be provided in order to avoid floor heaving.

And sometimes steel ribs with lose backfill are also used to release the strain energy in a controlled fashion. That is in this case you will have the tunnel closure more than 4% shall not be permitted. What are the precautions that one needs to keep in mind? We need to increase eternal diameter to absorb desirable closure. We need to provide the invert support as early as possible to mobilize full support capacity.

And long-term instrumentation is essential. Circular shape is ideal in this case as well. Coming to the next category of the ground condition which is the swelling ground.

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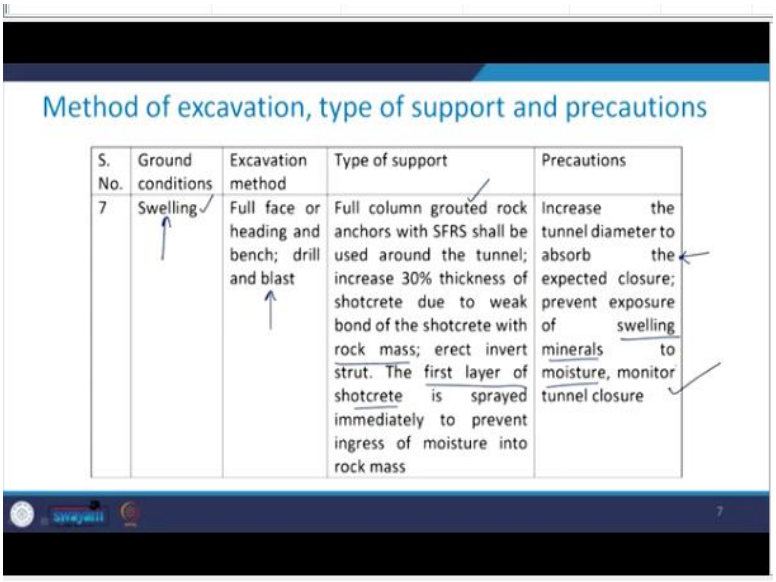

The excavation method is full face or heading and bench, drill and blast. The type of support includes full column grouted rock anchors with SFRS and it should be used around the tunnel. One needs to increase 30% thickness of the shotcrete due to weak bond of the shotcrete with that of the rock mass. The first layer of the shotcrete is sprayed immediately to prevent the ingress of moisture into the rock mass.

You know that in case of the swelling ground condition it is the ingress of the moisture which is the cause of all the problems because the moment those swelling causing mineral, they come in contact with water they show such characteristic like swelling. So, therefore if you just spray the first layer of the shotcrete immediately this will prevent the ingress of the moisture into the rock mass.

And therefore, this swelling characteristic can be controlled to some extent. Again, in this case the need to increase the internal diameter to absorb the expected closure, prevent exposure of the swelling mineral to the moisture and we need to monitor the tunnel closure that means instrumentation is required in this case as well.

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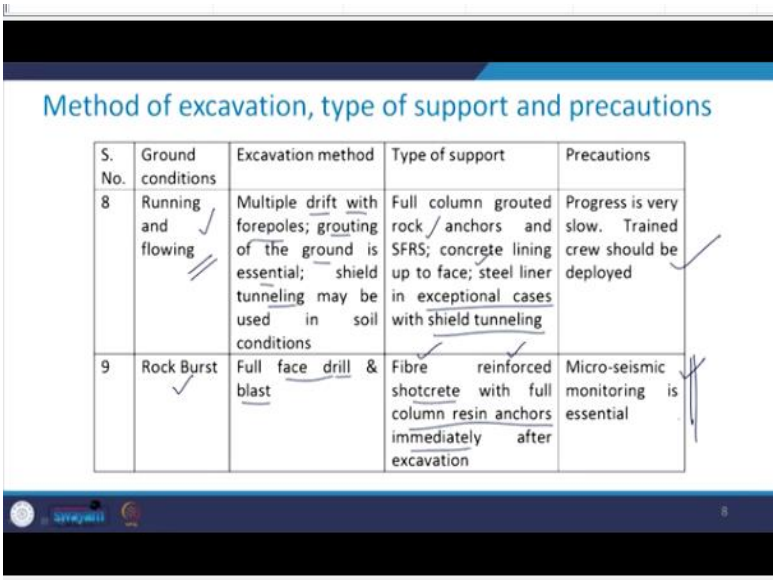

Next ground condition includes running and flowing and the excavation method that is recommended is multiple drift with fore-poles. Grouting of the ground is essential in this case, shield tunnelling may be used in the soil condition, in the previous class we discussed about this shield tunnelling. Full column grouted rock anchors and SFRS they are one of the recommended types of support for ground conditions which are running and flowing.

Concrete lining up to the face, steel liner should be provided in exceptional cases with shield tunnelling. Progress is very slow and, in this case, trained crew should be deployed as far as the construction activity is concerned in running and flowing ground conditions. Next category includes the rock bust, which has full phase drill and the blast method as one of the most suitable excavation methods.

The type of support which should be adopted includes fiber reinforced shotcrete with full column resin anchors and it should be provided immediately after the excavation. In this case, micro seismic monitoring is essential because this rock blast says sudden release of the energy and it takes place in case of the hard rocks. So, therefore, this is essential that is micro seismic monitoring.

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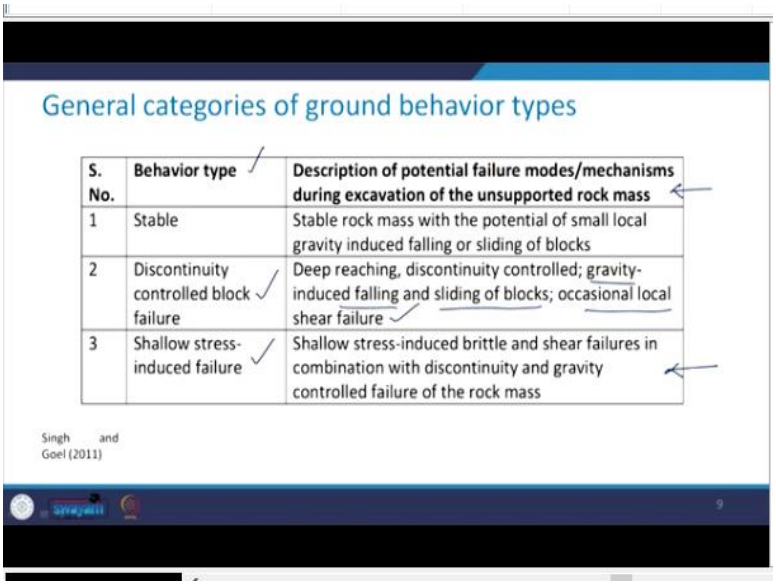

Coming to the general categories of ground behaviour types. So, the second column gives me the idea about the behaviour type. And the last column talks about the description of potential failure modes or mechanisms during excavation of the unsupported rock mass. First behaviour is the stable behaviour. What happens or what is the description? That is in this case stable rock mass is there with the potential of small local gravity induced falling or sliding of the blocks from the side walls of the tunnel.

Next category is discontinuity-controlled block failure and its description include deep reaching, discontinuity control, gravity induced falling and sliding of blocks and occasional local shear failure can also be observed. The third category include shallow stress induced failure and the description is like this, which is shallow stress induced brittle and shear failures in combination with discontinuity and gravity-controlled failure of the rock mass.

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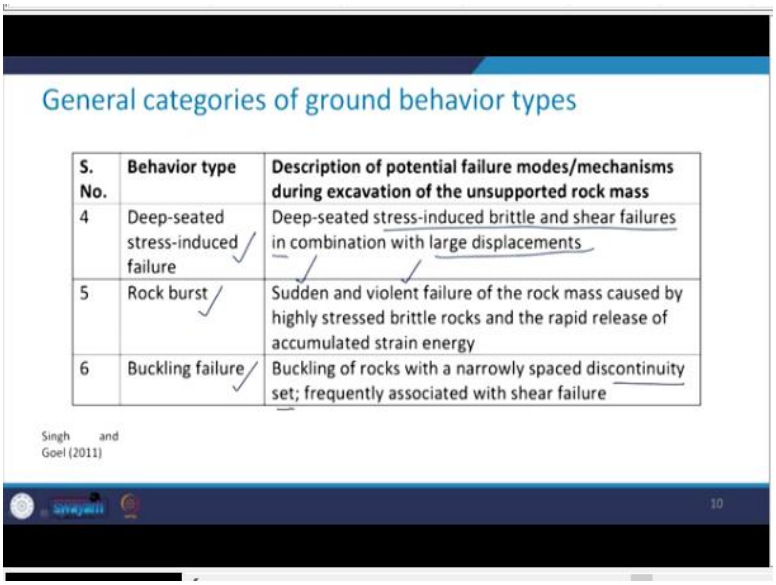

The fourth category of the behaviour is deep seated stress induced failure. In this case, deep seated stress induced brittle and shear failures in combination with large displacements may take place. In case of the rock burst, it is the sudden and violent failure of the rock mass that is caused by highly stressed brittle rocks and the rapid release of accumulated strain energy. The sixth one is the buckling failure in which the buckling of rocks takes place with a narrowly spaced discontinuity set and it is frequently associated with the shear failure. Next category has shear failure under low confining pressure.

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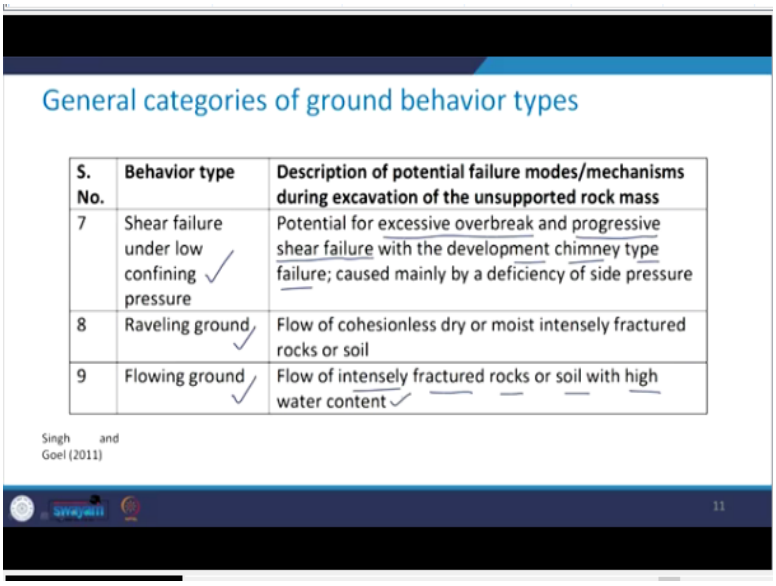

This has potential for excessive overbreak and progressive shear failure along with the development chimney type failure and this is caused mainly by a deficiency of the side pressure. In case of the raveling ground, it is the flow of cohesionless dry or moist intensely fractured rocks or soil. However, in case of the flowing ground it is the flow of intensely

fractured rocks or soil with high water content. So, you need to be clear about that what is the difference between ravelling ground and flowing ground? In case of the flowing ground, it is associated with the high-water content.

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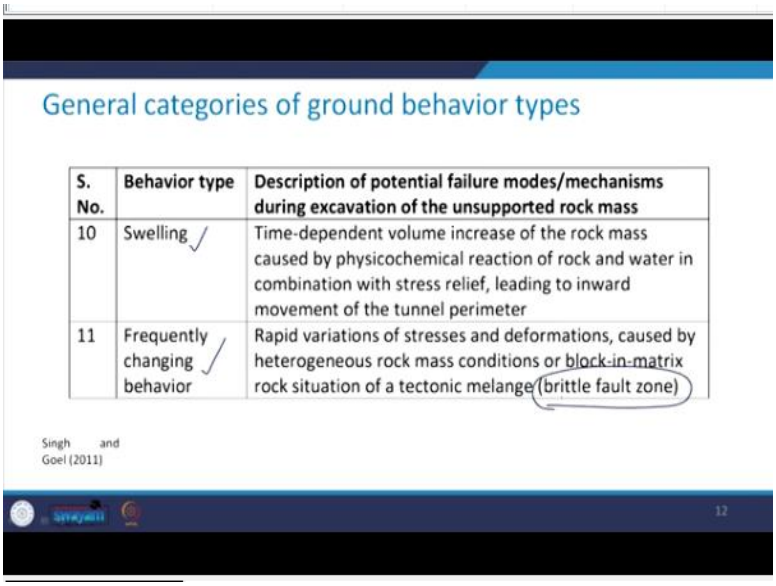

Next behavior type is the swelling and it involves time dependent volume increase of the rock mass which is caused by physical chemical reaction of rock and water in combination with the stress relief and it leads to the inward movement of the eternal perimeter. This I have already explained to you in some of the earlier slides. In case if the grounds behavior is such that it is changing quite frequently then that falls under this category. It has the rapid variations of stresses and deformation.

It is caused by the heterogeneous rock mass conditions or block in matrix rock situation of tectonic melange, that is brittle kind of the fault zone.

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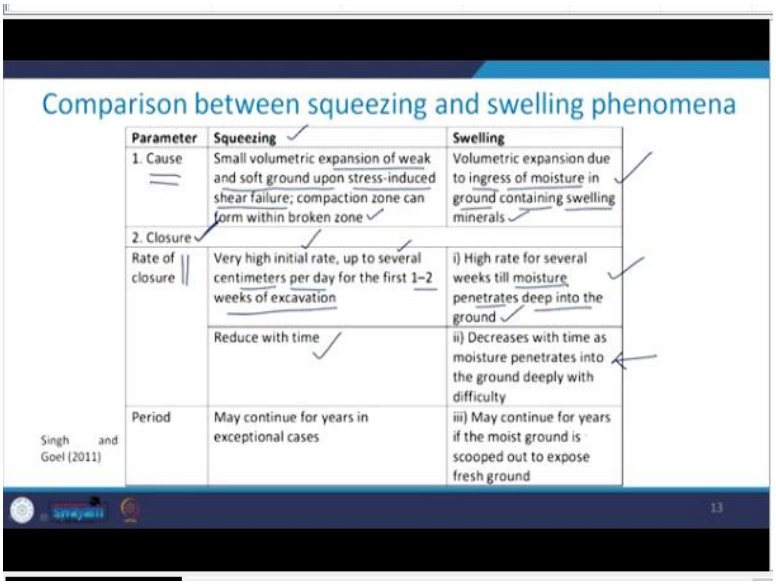

Now this was all about the various ground behavior and their description. We have been learning about the squeezing and the swelling ground condition. Let us try to have a look that what is the comparison between these phenomena? That is squeezing and swelling phenomena. So, the first column here gives you the idea about the parameter for which we are going to compare these 2 phenomena, that is squeezing and swelling.

And the second column corresponds to for the squeezing condition and the last column is for swelling condition. So, the first parameter is cause. What causes the rock masses to squeeze or to swell? In case of the squeezing rock mass theory small volume metric expansion of weak and soft ground upon stress induced shear failure. Compaction zone can fall within the broken zone. However, what happens in case of the swelling phenomenon? The volume expansion is because of the ingress of the moisture in the ground containing swelling minerals.

There is a difference between squeezing and swelling causing parameter in squeezing case it is the stress induced shear failure while in case of the swelling it is the ingress of mass. The second parameter is the closure. And in this closure, first we have the rate of closure that is on the basis of the rate of closure. These 2 phenomena they are differentiated. In case of the squeezing condition, it has very high initial rate.

And it can be up to several centimetres per day for the first 1 to 2 weeks of excavation and in case of the swelling ground it is the higher rate for several weeks till moisture penetrates deep into the ground. Rate of closure in case of the squeezing ground condition reduces with time

and in case of the swelling condition it decreases with time as the moisture penetrates into the ground deeply with great difficulty.

The next aspect is the period of this closure, this may continue for years in some of the exceptional cases for the squeezing phenomena, while in case of the swelling phenomenon it may continue for years if the moist ground is scooped out to expose fresh ground.

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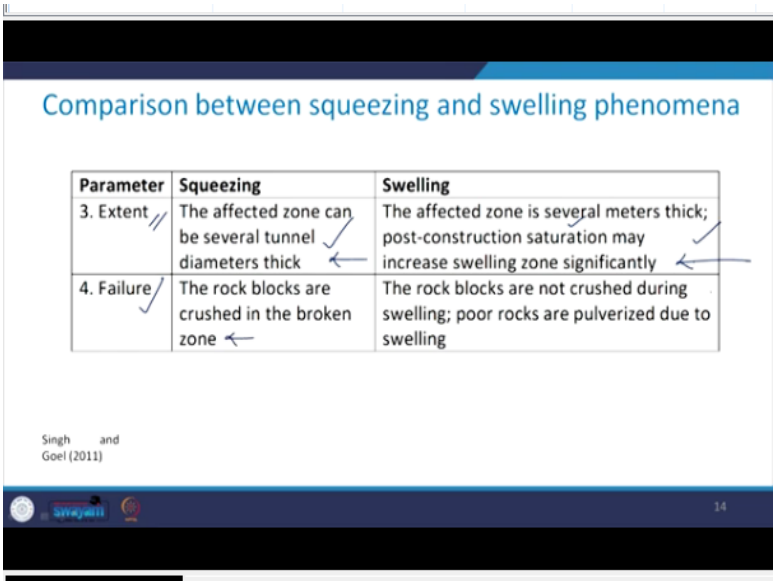

The extent is the third parameter on basis of which these 2 phenomena have been differentiated here. The affected zone in case of the squeezing ground condition can be several tunnel diameters thick. So, if the tunnel diameters say for example is 10m then the affected zone can be say, 50, 60 meters thick, in case of the squeezing ground condition. However, in case of the swelling ground condition the affected zone is several meters thick. Post construction saturation may increase swelling zone significantly.

So, that is the difference between swelling and the squeezing phenomena, as far as the extent is concerned. Coming to the parameter concerning the failure, in case of the squeezing condition the rock blocks are crushed in the broken zone. However, in case of the swelling condition the rock blocks are not crushed but poor rocks are pulverized due to swelling. So, that's one of the major differences as far as the squeezing and swelling phenomena is concerned with respect to failure.

Rock blocks are crushed in the broken zone in case of the squeezing phenomenon and when the swelling phenomenon is taking place these are not crushed. Poor rocks are pulverized due

to this phenomenon or due to this ground condition. So, these are some of the parameters based upon which the swelling and squeezing conditions they can be differentiated. So, in today's class we learned about the method of excavation, type of support and the precaution to be taken for different ground conditions.

Then we saw that what is the type of the behavior for these different ground conditions and their description and finally we saw that what is the difference between squeezing and swelling phenomena with respect to various parameters. In the next class we will learn about the elastic analysis of the circular tunnels. Thank you very much.