Rock Engineering
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Lecture-35
Tunneling: Underground Excavations

Hello everyone. In the previous class, we finished our discussion on various strength criteria, which are applicable in case of rocks and rock masses. Today we will start our discussion on a fresh topic, which is one of the applications in the area of rock engineering. And we are going to take up the first application area that is tunneling. Today we will learn about various underground excavations as far as tunneling is concerned, and also, we will learn about various ground conditions.

So, first I will tell you that what all are the different ground, underground excavation that is what is the difference between tunnel, shaft, cavern, drift, adits etc. Because these terms are going to come across to you quite often when we have our discussion in this chapter or when you go to the field and when you work on the project related to the tunneling in rocks or rock masses. Then there it is very important for you to first learn about different types of this underground excavation before you learn about their elastic, elasto-plastic analysis.

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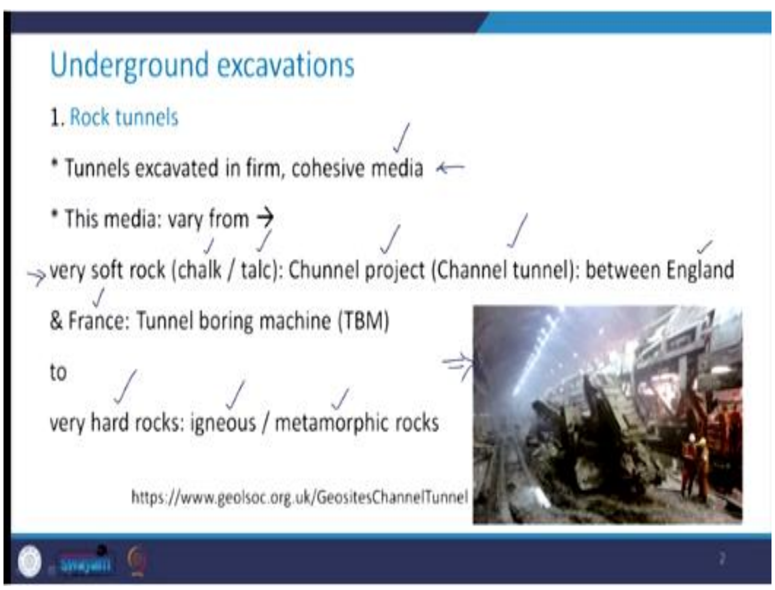

So, to start with first term is your rock tunnels. When I say rock tunnels, these are the tunnels excavated in firm, cohesive media. This media can vary from very soft rock which can be chalk or talc like Chunnel project called as channel tunnel. This is a tunnel between England and France and which was constructed using tunnel boring machine. What is that tunnel boring machine? We will discuss, I will show you with the help of few pictures that how it looks like.

So, this media varies from very soft rock like chalk or talc to very hard rock's which maybe of igneous or metamorphic type. This is a picture showing a view of the Channel tunnel during it is construction. It is not easy to have the construction of the tunnel through very soft rock, because of the associated difficulties in terms of it is stability, strength characteristic, standup time etc.

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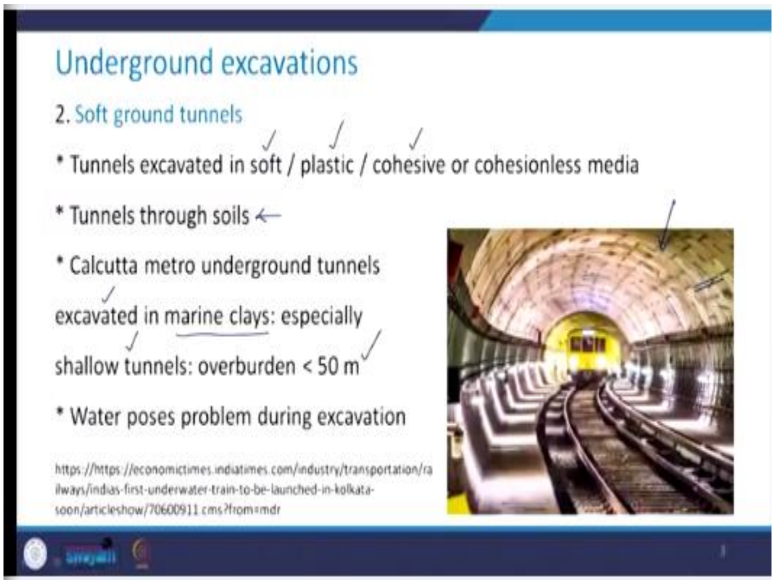

The second one is soft ground tunnels. As the name suggests, these are the tunnels excavated in soft plastic cohesive or cohesionless media, tunnels through soils fall in this category. Calcutta metro underground tunnels, these were excavated in marine clays especially shallow tunnels with overburden less than 50 meter, in this case water poses problems during excavation. Now this is a picture which belongs to the project that is going to be India's first underwater train which is to be launched in Kolkata very soon.

So, these pictures are giving you the idea that where are all these terminologies, where all this knowledge that we are going to discuss in some of the subsequent classes are going to be useful.

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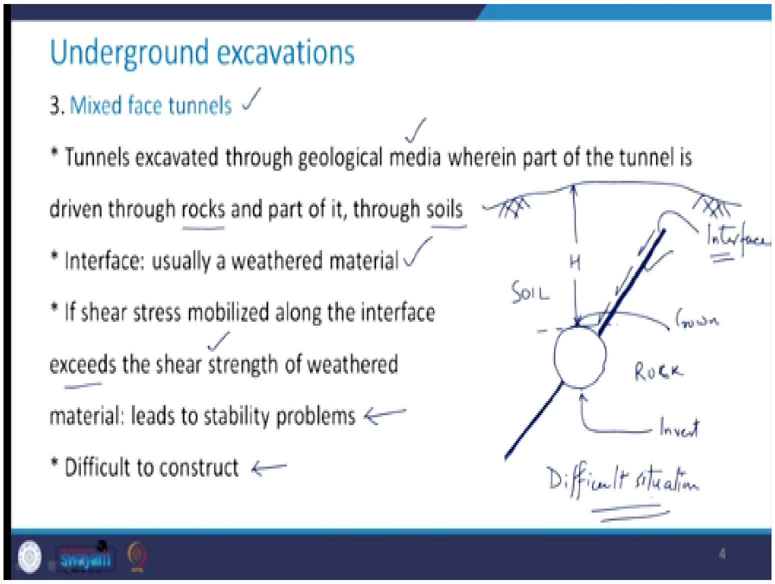

Then you have the third one which is the mixed phase tunnels, till now you have seen that either it was through rocks or you had through the soil or the soft rocks. But in this case tunnels are excavated through the geological media where part of the tunnel is driven through rocks and part of it through soils. So, see it looks like this. Say this is your tunnel cross section and say this is the interface which is continuing on this side as well like this.

Now here on this side and say here it is your ground surface the top last point of the tunnel is called as the crown of the tunnel and the bottom most point is called as the invert of the tunnel. So, from this top point the height of the ground is H which is called as the overburden. Now on this side you have soil and, on this side, you have the rock. So, in this case this is what is your interface and this is usually a weathered material.

Now what happens is because there is a difference in the material and this interface is a weathered material, what happens is there is going to be the mobilization of the shear stresses. Now what happens is if this shear stress which is mobilized along this interface exceeds the shear strength of the weathered material, it leads to various stability problems. And therefore, this mixed phase tunnel is quite difficult to construct.

So, remember that mix phase tunnels they are the tunnels which are excavated through the geological media wherein part of the tunnel is driven through rocks and part of it through the soils. The interface is a weathered material and whatever is the shear stress that is mobilized all along the interface. If this exceeds the shear strength of this weathered material, then this leads to the stability problem.

So, this is a difficult situation as far as the construction is concerned. Next one is the shield tunnels, they correspond to shield tunneling which is a construction methodology adopted for the construction of soft ground tunnels.

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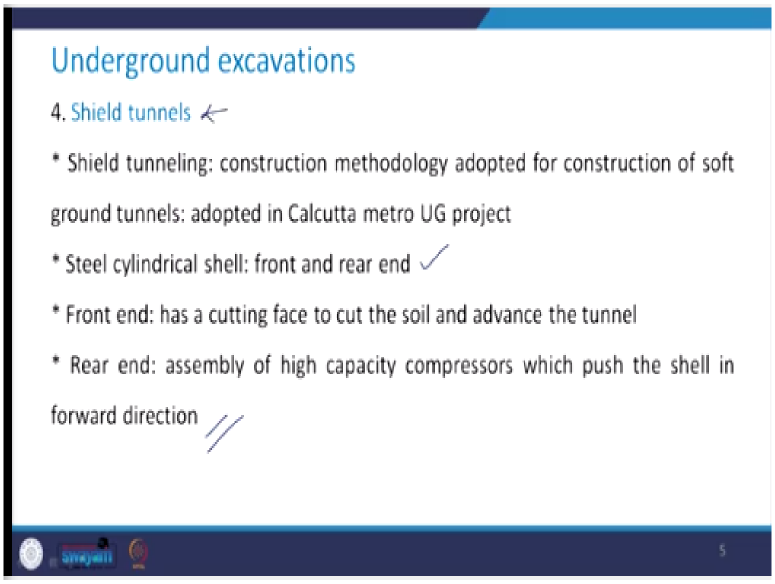

And this was also adopted in Calcutta metro underground project. In this case, we have steel cylindrical shell at the front and rear end. Front end has a cutting face, which cuts the soil and advance the tunnel. However, the rear end comprises of assembly of high-capacity compressors which push the shell in the forward direction. So, basically these shield tunnels are defined with respect to the construction methodology involving shield tunneling.

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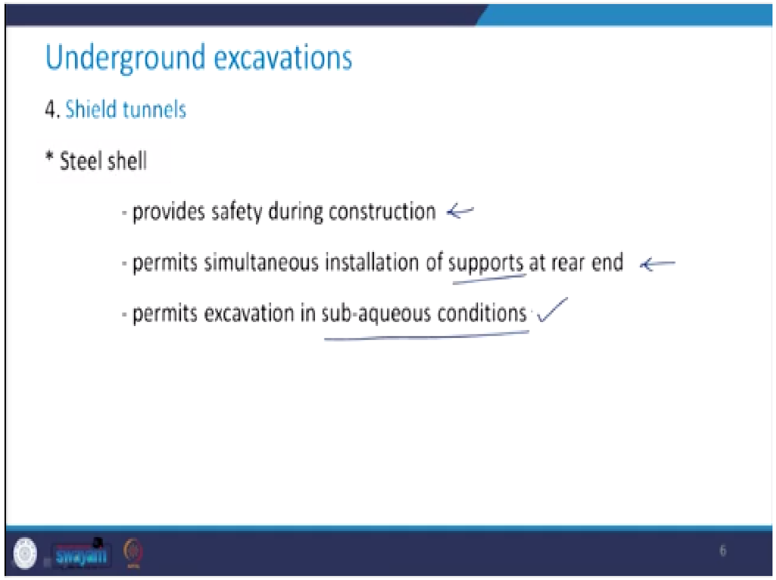

This steel shell will provide safety during the construction; they permit simultaneous installation of supports at the rear end. And also, they permit excavation in sub-aqueous condition that is when in case if you have the tunnel construction in the presence of the water, there are also this help.

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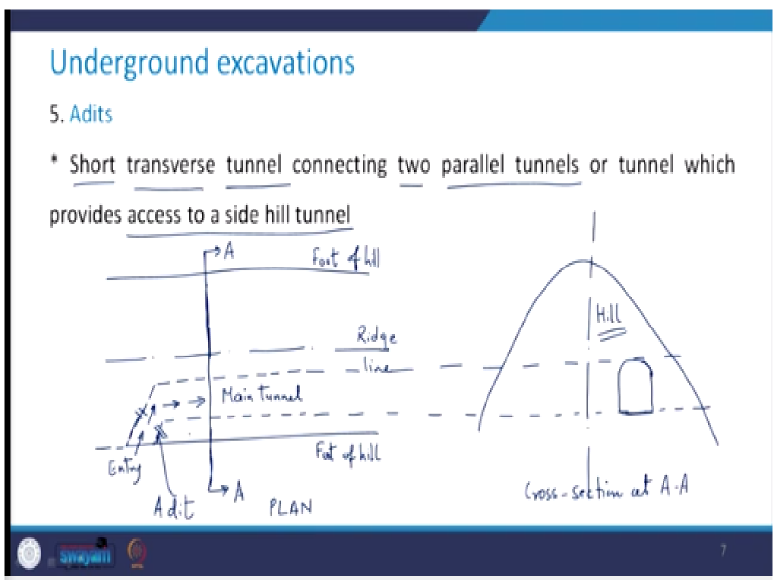

Coming to the next category which are the adits, these are the short transverse tunnel which connect two parallel tunnels or tunnel which provides access to the side hill tunnel. See, this is how it looks like, let us say that in the plan. Say this is a plan where this is foot of hill and obviously this will also be foot of hill. So, I will have here say, a section, say this is a section A, A.

Then we have this ridge line and this is how the main tunnel is in plan. So, this is I am drawing a plan. So, if I just have this kind of structure which is used for entry to the main tunnel, so this is your main tunnel, this is entry, so this is called as adit. And how it will look like, if I just take the cross section along this section A-A, so how this is going to look like is this. So, I will have this hill and just project it this side, this is how your tunnel will look like in the cross section at A-A that is this section, and this is what is your hill.

So, this is the short transverse tunnel connecting either two parallel tunnel or a tunnel which provides access to the side hill tunnel as here I have shown one example of this access to the side hill tunnel. So, this is what is called as, this portion is what is called as the adit.

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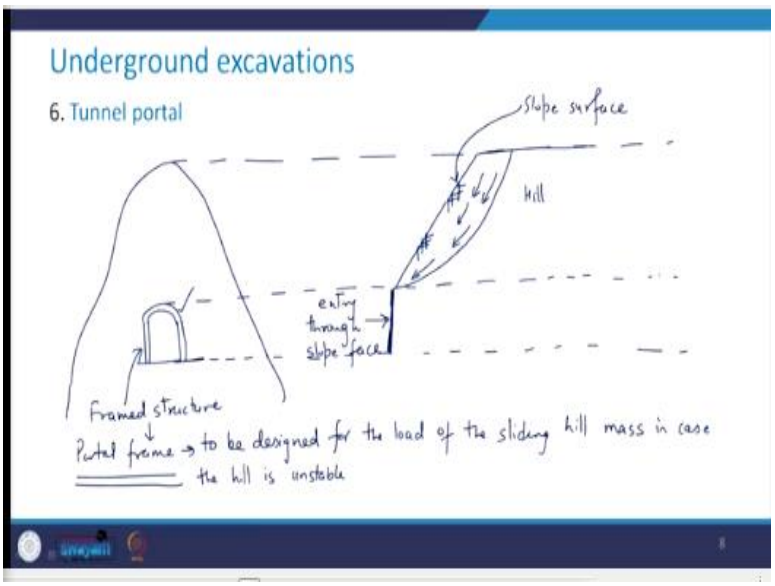

The next one is the tunnel portal, see this is how it will look like, so we have the hill let us say that is the hill and here we have a frame structure like this. So, this is what is your framed structure. Now just take the projection and say here you have the slope face and this is what you have entry through slope face. Now see there is going to be this kind of failure surface maybe there. So, this portion is of hill and this is what is your slow surface, this is your ground level.

There will be this kind of tendency for thus material to slide. So, there is this framed structure which is called as the portal frame and this should be designed for the load of the sliding hill mass, in case the hill is unstable. So, in case if this portion has a tendency to slide then this portal frame should be designed in such a manner that whatever is the load because of this sliding mass, this portal frame should be able to take that much of the load. So, this kind of frame structure is called as the portal frame and also called as tunnel portal.

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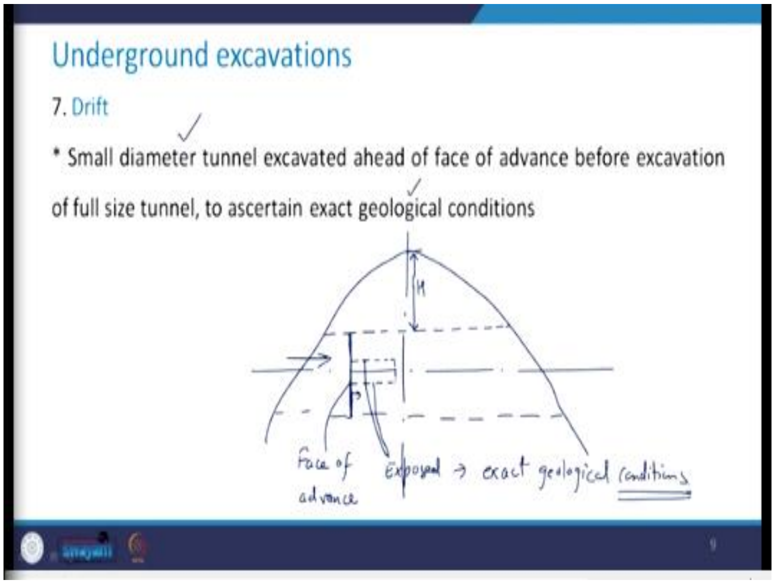

The next one is the drift. Drift is the small diameter tunnel excavated ahead of face of advance before excavation of full size of the tunnel; this is used to a certain exact geological condition. So, in case of the rocks lot of uncertainty maybe there and we may not be aware of the exact geological conditions, from the conditions what are exposed at the surface. So, in order to ascertain about that one needs to go for these small diameter tunnels.

So, see this is how it looks like. So, I have here as a rich line and say this is your hill and this is the say axis of the tunnel. Now, this is saying the part or the crown portion of the tunnel and here you have invert portion. So, the overburden is this much which is H. Now this is the face of the advance. So, the tunnel has been excavated up to displace let us say the tunnel is being excavated in this direction and up to this phase, it has already been excavated.

Now we want to be ascertain about the exact geological condition beyond this point. So, what we will do is we will excavate a small diameter tunnel here. So, once we excavate this tunnel what will happen is that these two surfaces they are going to be exposed now. And since these are exposed now, we can take a look at it and then take the field observation like what are the joint conditions etc, in order to get the exact geological conditions. So, this is how this drift is useful.

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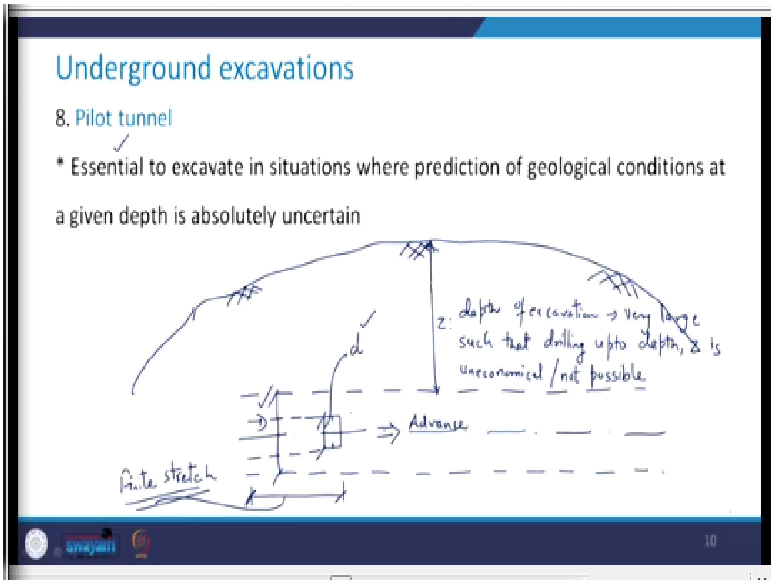

The next category is the pilot tunnel. This is essential to excavate in situations where prediction of geological conditions at a given depth is absolutely uncertain. In what situation it will be when there is a lot of variation in the geology, even at the surface. And we cannot be sure that what it is going to be at any particular given depth. Or let us say that your bore data or core log data is giving you lot of variation as far as the type of the rock which is encountered all along the depth is concerned.

In that case, it is essential to go for the pilot tunnel, see this is how it looks like. So, say this is your ground surface, now here at a depth one is to go for the tunnel construction. So, this is the center line or the tunnel axis. This tunnel has a diameter of say capital D and here you will have small tunnel, say which is of the diameter say small d. And obviously from here to here, this is going to be the finite stretch, and this is the direction of the advance of the tunnel.

This is say, the depth Z, which is the depth of excavation and this is very large such that drilling up to this depth Z is uneconomical or it is not possible. So, in that case we need to go for this pilot tunnel excavation having a diameter smaller than the diameter of the main tunnel. Obviously, this will be done for the finite stretch and once this pilot tunnel is excavated, then one can get the idea about the geological conditions which are exposed at these surfaces of this pilot tunnel.

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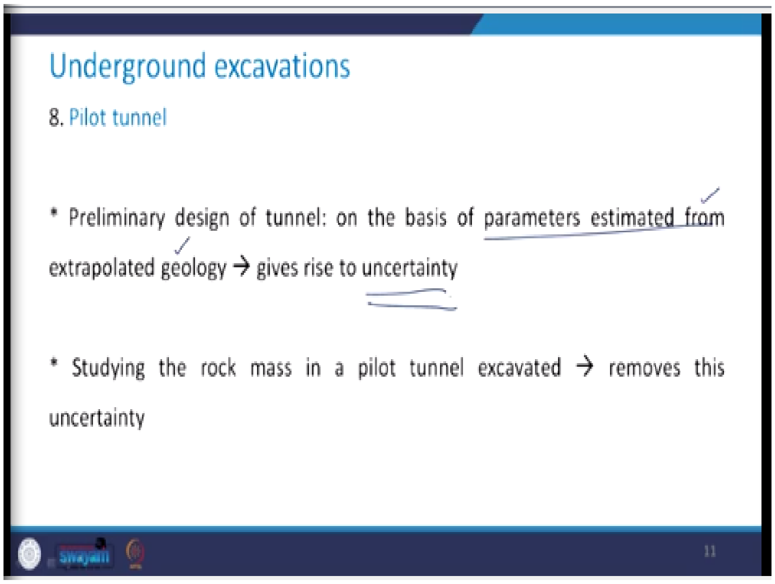

So, as far as the pilot tunnel is concerned the preliminary design of the main tunnel on the basis of the parameters which are estimated from the extrapolated geology, they give rise to the uncertainty. And therefore, studying the rock mass in a pilot tunnel which has been excavated, it removes all these uncertainties. And therefore, this pilot tunnel in the cases where it is really not possible to go for the rock exploration up to that depth is very, very useful.

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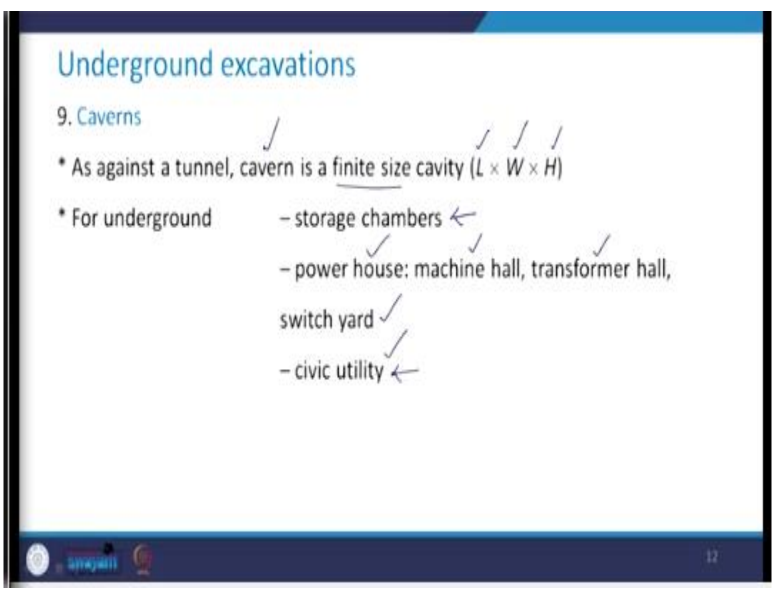

The next category is the caverns. As against the tunnel cavern is a finite size cavity which has some finite length, width and height. You have seen that in case of the tunnel, it has a cross section but it is length perpendicular to that cross section is pretty large as compared to it is cross sectional dimension. Or maybe I can say that it is length is much larger as compared to it is diameter.

But in case of the cavern all the three dimensions are finite and compared to each other they are of significant magnitude, where these are used? For underground storage chambers, for underground power houses, in power houses you know that there are different components like machine hall, transformer hall, switch yard. So, for all these things one needs to go for the construction of the cavern. Then for underground civic utility also these caverns are constructed. Now coming to the next category, which is the shafts.

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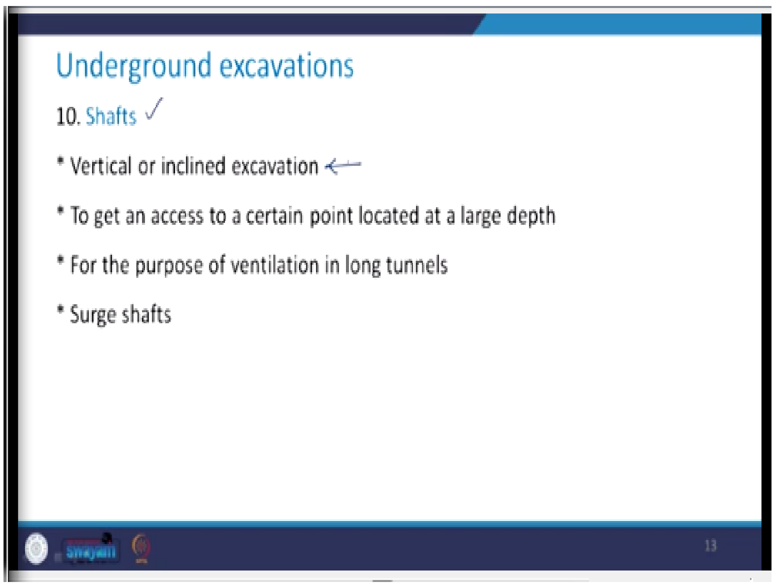

These are vertical or inclined excavation and used to get an access to a certain point located at a large depth. They are also used for the purpose of ventilation in long tunnels; they are used in the case of the surge shafts.

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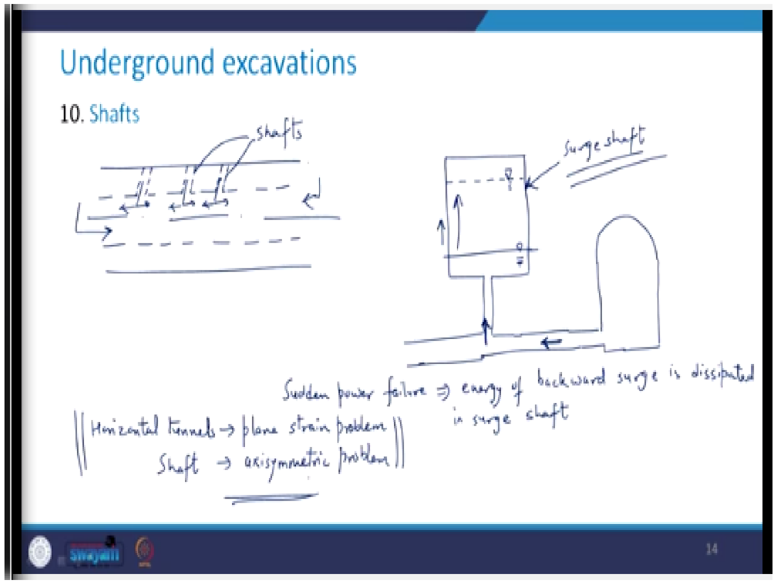

Let us see with the help of few figures that how these shafts they look like. So, say here you have the tunnel and then at few places along the length of the tunnel you have this kind of inclined excavation. So, this is the way that you enter in the tunnel, then here this way or this way, so these are shafts. In case of the surge shafts, what happens? See, it looks like this, so this is what is your surge shaft, it is connected to the chamber, say this is what is your water level which can rise up to this.

So, this is what is the surge shaft. So, what happens in case you have the sudden power failure? What happens in this case? The energy of backward surge is dissipated in the surge shaft. So, you see that suddenly I mean it will have this space here, so this water level which was here and suddenly if there is a power failure. So, this will go here and certainly there is going to be the rise in this level which can be accommodated in case of the surge shafts.

So, in case if we have the horizontal tunnels then it is a problem of plane strain, you remember we discussed about plane stress and plane strain problems. In case of shafts, it is the axisymmetric problem. Please keep this in mind, an important aspect. So, this was all about various underground excavations, depending upon their size, the purpose for which that they are being constructed, you can divide it into several categories as we discussed. Now let us learn about some of the ground conditions in tunneling.

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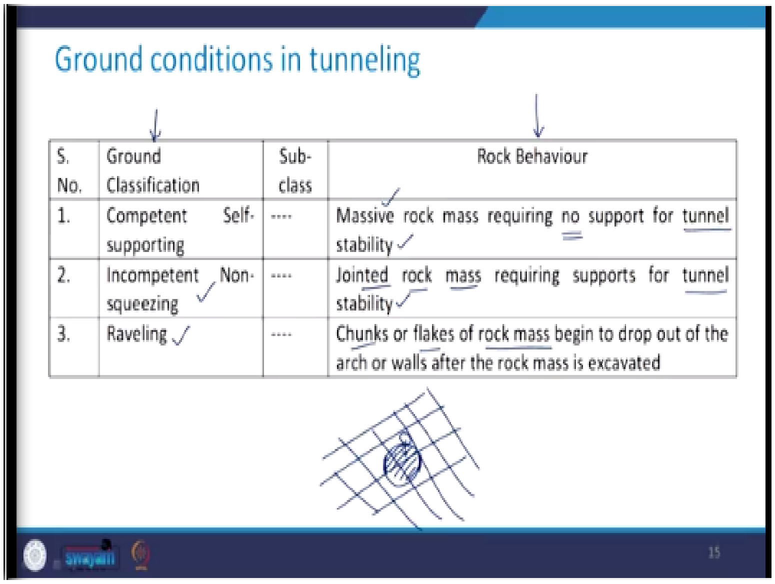

So, here the second column gives you the idea about the ground classification, and the last column talks about the rock behaviour. So, when we say that the ground is competent self supporting, what does that mean? This means that, it is comprising of massive rock mass which requires no support for the tunnel stability. That means if you have the excavation through the competent self-supporting rock, then that tunnel may not need any kind of support for it is stability.

The second category is incompetent non squeezing, this has jointed rock mass and it requires support for the tunnel stability. The third one is the raveling ground condition, in this one chunks are flakes of the rock mass they begin to drop out of the arch or walls after the rock mass is excavated. So, let us say that you have this kind of say rock mass with some let us say joints or whatever it is, with some kind of joints or discontinuities and then you excavate like this.

So, this is what has been excavated. Now, what will happen that it may happen, now there can be few blocks which are loose either in the roof part or here at the side which may either fall or slide along the tunnel wall. So, this kind of ground condition is called as raveling.

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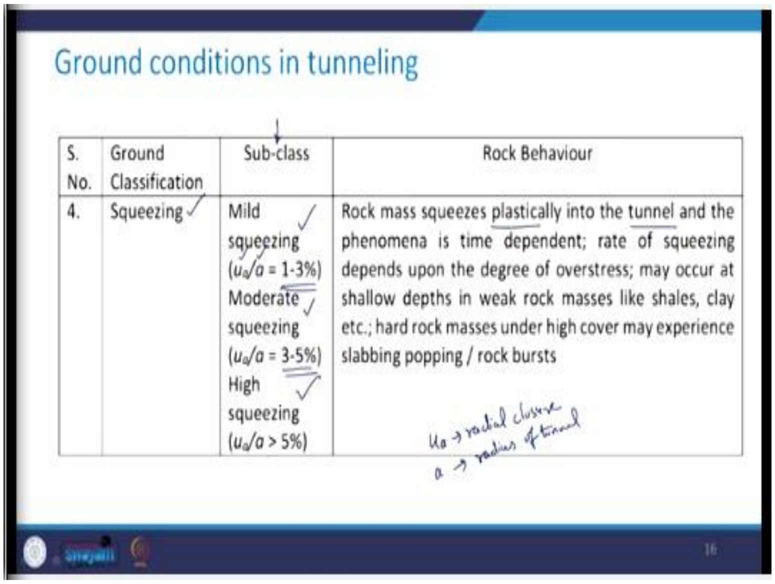

S. No.	Ground Classification	Sub-class	Rock Behaviour
4.	Squeezing	Mild squeezing (u_a/a = 1-3%) Moderate squeezing (u_a/a = 3-5%) High squeezing (u_a/a > 5%)	Rock mass squeezes plastically into the tunnel and the phenomena is time dependent; rate of squeezing depends upon the degree of overstress; may occur at shallow depths in weak rock masses like shales, clay etc.; hard rock masses under high cover may experience slabbing popping / rock bursts

The fourth one and the very important, and these needs a lot of care is squeezing. It has various subclasses, first let us see what do we mean by the squeezing ground condition and then I will explain you that why it is divided into some different sub classes. So, the squeezing rock mass is the plastic, it squeezes plastically into the tunnel and this phenomenon is time dependent. The rate of squeezing it depends upon the degree of overstress.

It may occur at shallow depths in weak rock masses such as shales and clays. Hard rock masses under high cover may experience slabbing, popping or rock burst. So, based upon the way that it is getting squeezed or based upon the amount of the radial closure that the rock mass is experiencing this category is divided into some number of subclasses. For example, you have mild squeezing, in this case u a upon a is 1 to 3%, this u_a is the radial closure.

Moderate squeezing is 3 to 5%, a is the radius of the tunnel, and high squeezing include u a upon a to be more than 5%, why we need to be careful about it? That if the rock mass is squeezing and say you want to construct a tunnel of say 10m diameter, then you have excavated and the rock mass has this characteristic of squeezing, so what will happen? If you leave it unsupported for let us say, sometime what will happen?

It will start squeezing and the tunnel diameter will reduce, and it will not be as 10m which is required. So, we need to be extra careful in case if we encounter this type of ground condition.

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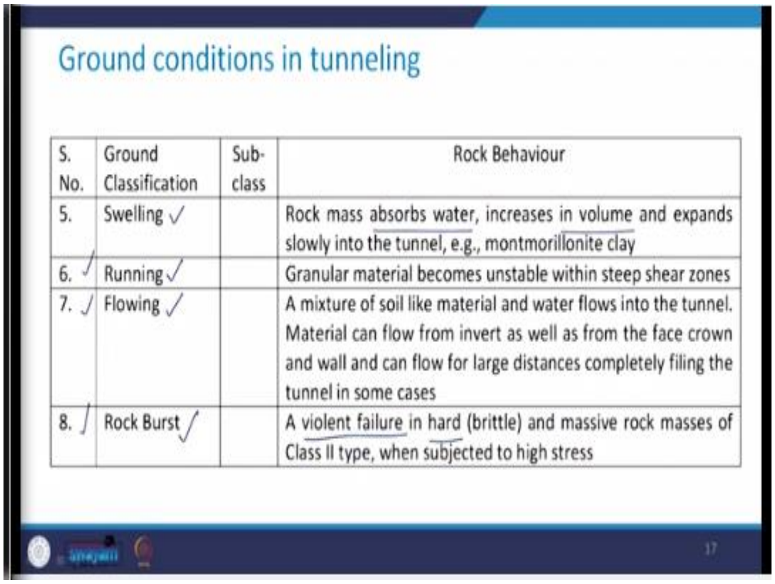

Ground conditions in tunneling

S. No.	Ground Classification	Sub-class	Rock Behaviour
5.	Swelling		Rock mass absorbs water, increases in volume and expands slowly into the tunnel, e.g., montmorillonite clay
6.	Running		Granular material becomes unstable within steep shear zones
7.	Flowing		A mixture of soil like material and water flows into the tunnel. Material can flow from invert as well as from the face crown and wall and can flow for large distances completely filing the tunnel in some cases
8.	Rock Burst		A violent failure in hard (brittle) and massive rock masses of Class II type, when subjected to high stress

The next category is the swelling. In this case rock mass absorbs water, it increases in volume and it expands slowly into the tunnel. So, wherever you have this mineral like montmorillonite, you will have such type of characteristic in the rock mass. Next ground condition is the running ground condition, in which the granular material becomes unstable within these steep shear zones.

In case of the flowing ground condition, a mixture of soil like material and water flows into the tunnel. This material can flow from invert as well as from the face crown and also from the wall, and can flow for large distances completely filling the tunnel in some cases, which is not desirable. So, one needs to be careful about such difficult ground conditions. Then the next one is the rock burst.

In this case, a violent failure in hard or brittle and massive rock masses of class II type occurs when these are subjected to high stresses. So, these are the some of the extreme conditions ground conditions. So, this is what that I wanted to discuss with you today. To summarize, we discussed about different underground excavations and some of the ground conditions which you may come across while going for the construction through rock or rock masses.

Here we are focusing on the construction of tunnels. In the next class, we will have some more discussion about these ground conditions, method of excavation and the support systems. Thank you very much.