Underground Space Technology
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Module No # 03
Lecture No # 11
Planning of and Exploration for Underground Construction Projects

In the previous class we learned about various ground condition and also, we saw that what is the difference between swelling and squeezing ground conditions. So, today we will learn about the planning of an exploration for underground construction projects. So, in this one, we will see whether we are able to work at a particular site or not or whether we should reject that site. So, there are few parameters based on which we will take such decisions so all those things we are going to learn in this class.

So, to start with let us learn about the planning aspects of underground excavations in rocks. So, the first step towards this includes identification of material through which the excavation is to be made.

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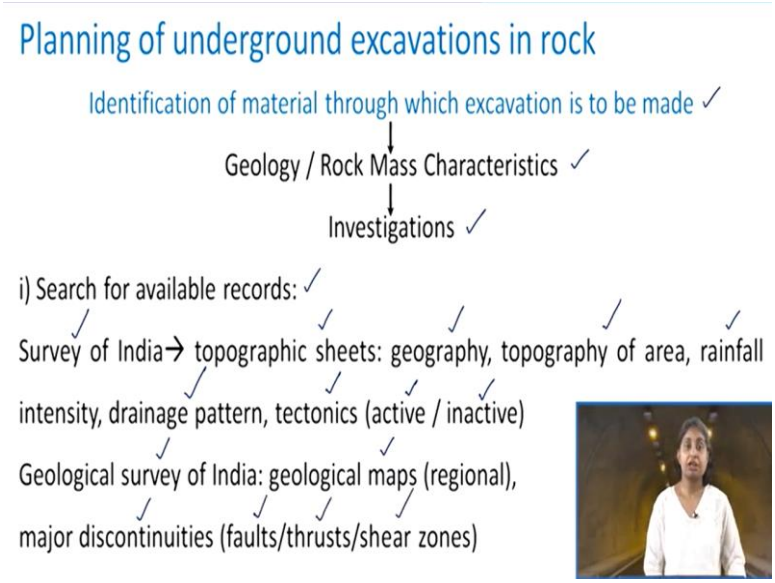

Now, this include the characterization of the geology or the rock mass and how can we carry out the characterization by taking up some investigations? Now, what all these investigations are let us take a look that first of all we need to search for the available records. Now from where these records are available, so the first sources survey of India. So, from here we can

take a look on topographic sheets which gives us the idea about geography, topography of the area, rainfall intensity, drainage pattern and the idea about the tectonic activities.

Whether that particular region is tectonically active or not? So, here we will get all this data from survey of India then second source is geological survey of India. This gives us the idea about the geological maps, regional geological maps then; major discontinuities such as fault thrusts and shear zones. So, first, we need to look for available records from survey of India and geological Survey of India.

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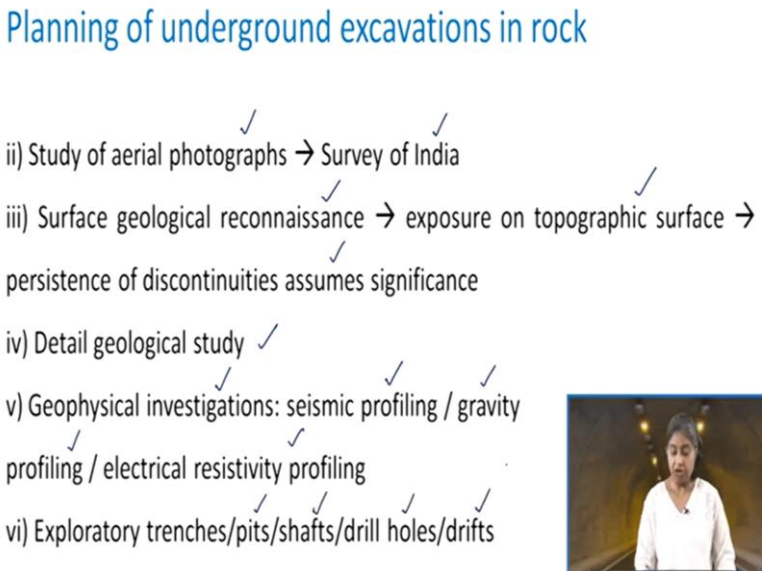

Then, we can study the aerial photographs and this we can get from survey of India. The next one that we need to carry out is surface geological reconnaissance that is this gives us the idea about the exposure on the topographic surface. And also, persistence of discontinuities that becomes important and it assumes the significance. Then, we need to carry out the detailed geological study also geophysical investigations. This includes seismic profiling gravity profiling and electrical resistivity profiling.

One can also go for exploratory trenches pits shafts drill holes or drift to get the idea about the geological structure at the site.

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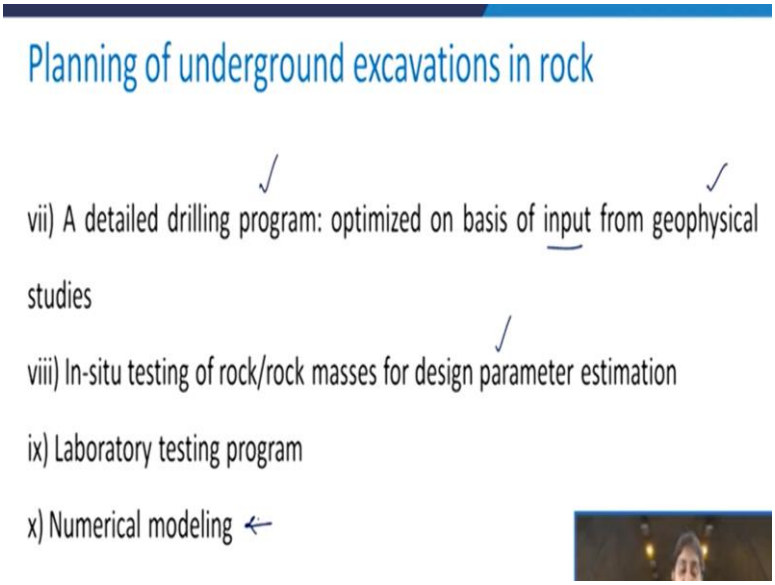

Then, we need to plan a detailed drilling program this is optimized on the basis of input from geophysical studies. Next step is going to be the in-situ testing of rocks or rock masses for the estimation of various design parameters. For example, let us say that you want to find out the shear strength parameters of the rock or the rock masses. So, in that case what we need to do is we need to carry out in-situ stresses.

Maybe, the direct shear test in the field to get those shear strength parameter, or let us say if you want to find out the state of in-situ stresses. So, we need to conduct the respective test like hydraulic fracturing in the field. In case, if you want to find out the deformation modulus of the rock mass then we need to carry out the respective test in the field. So, all these tests we are going to learn in this course.

Then, after the drilling program we can collect the samples from the field, this I have already discussed with you and those samples can be carried to the lab it can be transported to the lab. And there you can conduct a UCS test or Brazilian test or Tri-axial test to get the engineering properties of the rocks. Then the last step, include the numerical modelling, there are many situations where we really cannot simulate the exact situation which is there in the field experimentally.

So, in that case, we need to conduct the numerical experimentation, and that is what is called as numerical modelling. So, these days you have enough software's which are available software such as Comsol, Abaqus. There you can carry out numerical modelling and in case

of the rocks and rock masses, in fact, there is one software called UDEC. That is quite useful for the numerical modelling.

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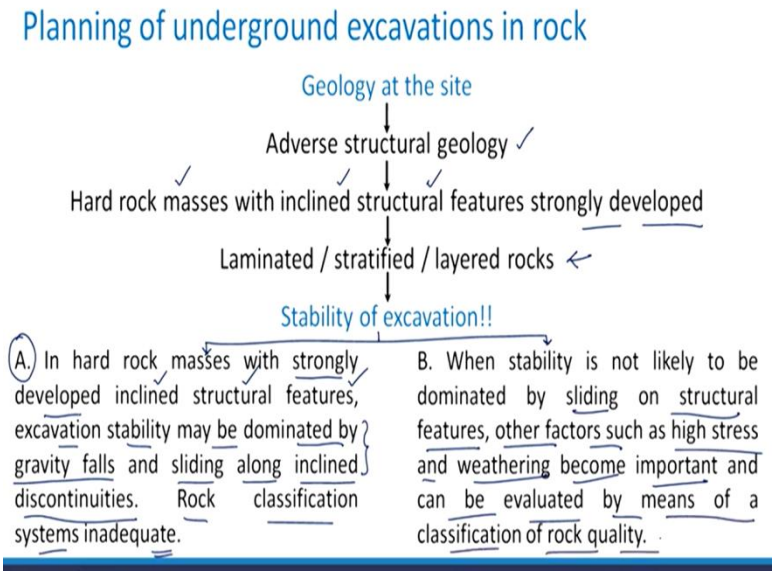

Now coming to the geology at the site, it is important for us to locate the adverse structural geology. This will give us the idea, about the hard rock masses with inclined structural features which are strongly developed. It also gives us the idea about the laminated stratified or layered rock. So, when you have such type of situation the stability of excavation is a matter of concern.

So, how about the stability of the concern what is the cause of the instability for the excavation? So, in this case, you can have 2 situations, A: this includes that in hard rock masses where you have strongly developed inclined structural features the excavation stability may be dominated by gravity falls and sliding along the inclined discontinuities. And if you have such type of situation the rock classification systems become inadequate.

When I talk about the rock classification system that will include RMR, Q, and GSI that we studied that is one aspect that is the excavation stability is dominated by gravity falls and sliding along the inclined discontinuities. Then the second portion is that, when the stability is not likely to be dominated by sliding on structural features. Then in that case other factors such as high stress and weathering become important and these can be evaluated by means of the classification of rock quality.

So, you see that when we have this, a condition their rock classification systems they are inadequate. But, in case, if you have B: situation there the classification of rock quality gives us the idea about the stability of excavation.

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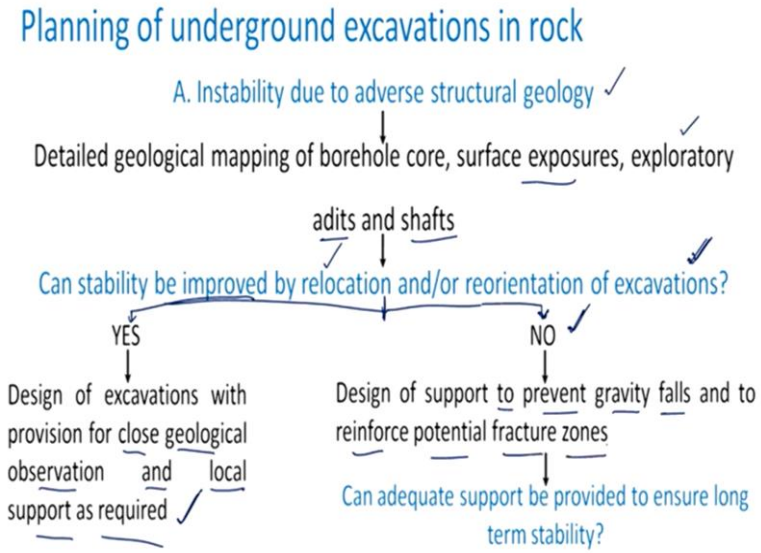

So, first we take, A situation that is when the instability is because of the adverse structural geology. So, in that case, the detailed geological mapping of borehole core surface exposures, exploratory edits and shafts it is needed. Then the question comes that whatever is the information that we get from these sources, exploratory adits and shafts. Then can we say that can the stability be improved by relocation or reorientation of excavation.

So, that is a question that comes in front of us, now if the answer to this question is yes, then in that case we will go to this particular column. And, if it is no, then we will come to this location. So, if the stability can be improved by relocation or the reorientation of the excavation then in that case, we designed the excavations with the provision for closed geological observations and local support as it is required

But, in case if the stability cannot be improved by relocation or reorientation of the excavation then the design of the support is carried out to prevent the gravity falls and to reinforce potential fracture zones. Then the next question that comes to us is whether the adequate support can be provided to ensure the long-term stability fine provided. Let us say, some kind of mesh to prevent the gravity falls or maybe reinforced locally those fractured zones with the help of, say rock bolts but then what about the long-term stability?

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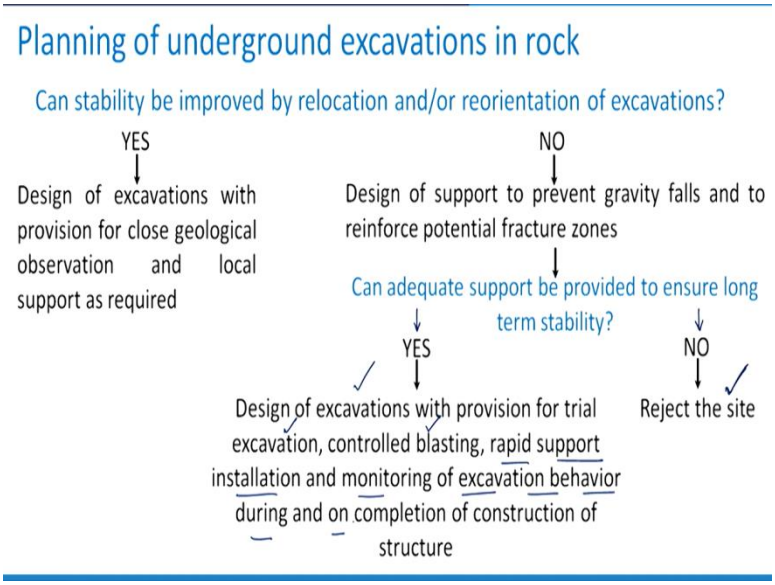

So, in that case, if the answer to this question is yes, we will go here and if it is no, we will come here. In case, if the adequate support system, cannot be provided to ensure the long-term stability then we have no option but to reject that site. But, in case, if the adequate support system can be provided so as to ensure the long-term stability. In that case, one needs to go for the design of excavations with the provision for trial excavation, controlled blasting rapid support installation and monitoring of excavation behaviour during and on the completion of construction of structure.

So, we need to be careful about the provision of trial excavation then we can limit the damage to the surrounding rock mass with the help of controlled blasting. Once the excavation is made immediately the support can be installed, and after the installation of the support system continuous monitoring of the excavation behavior during and after the completion of the construction of a structure should be carried out.

So, you see that this is a systematic approach following which we need to ensure that the proper support system is provided. There is the minimum disturbance to the surrounding rock mass, and then, the monitoring of the excavation behaviour is very important. Now, again we were discussing about this particular aspect so we focused on the point again I take you back to this particular slide.

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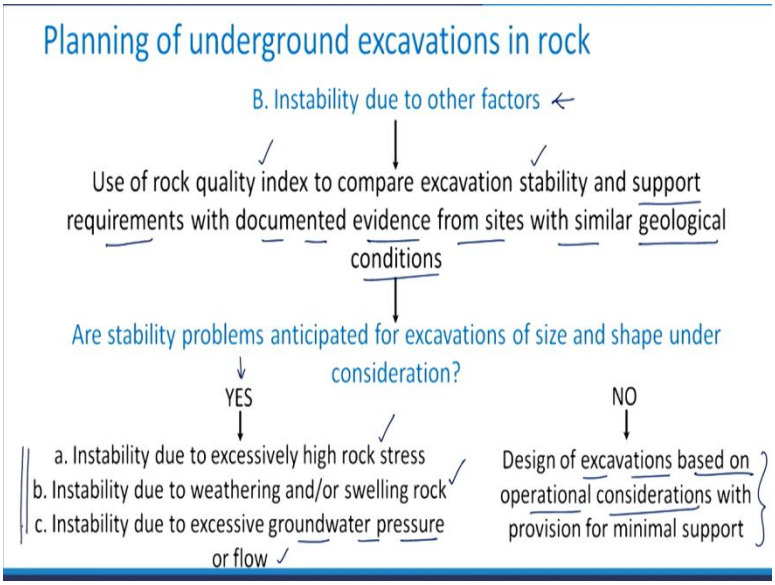

And now, let us focus on the other point, that is the aspect B, where the instability is due to other factors. Now, these other factors we have seen that, what these can be and there we also have seen that in such cases the classification systems can be helpful. So, here what we do is? We use the rock quality index to compare the excavation stability and the support requirements with documented evidence from these sites with similar geological conditions.

So, now the question in front of us is whether these stability problems are anticipated for the excavation of size and shape under consideration. Because you see that whatever are the rock mass classification systems, they give us idea a particular system is developed maybe for a particular type of tunnel. Or maybe, you can say that a particular type of structure in a particular type of rock mass.

So, in case, if you have the answer to this question as yes then there can be 3 situations, which will cause the instability. The first one is going to be instability due to excessive high rock stresses, then you can have the instability due to weathering or due to swelling rock, or the swelling ground condition. And then the third one is, the instability due to excessive groundwater pressure or water flow.

In case if the there are no stability problems, then simply what you will do is you will go ahead with the design of excavations, based on the operational considerations with the provision of minimal support. So, maybe let us say the, just you provide the shotcrete layer and maybe that will serve the purpose. So, the question now comes here that what about these three types of instability and how to tackle with them?

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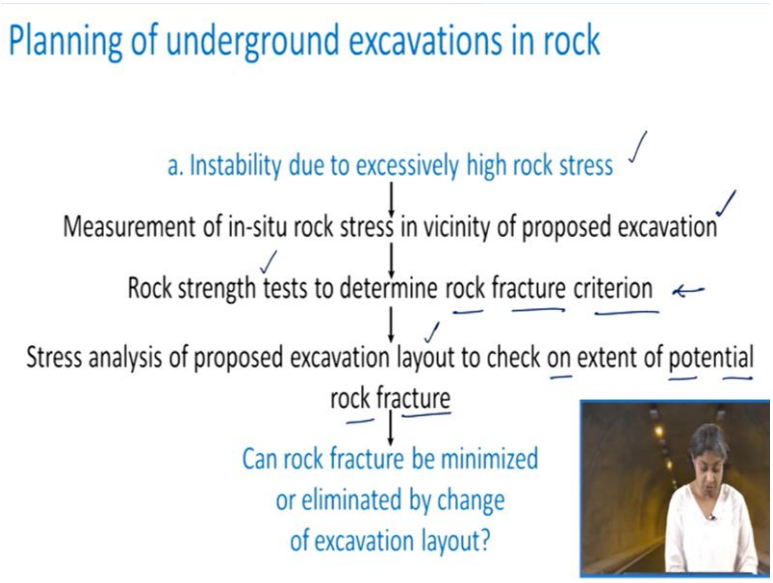

In case if the there are no stability problems, then simply what you will do is you will go ahead with the design of excavations, based on the operational considerations with the provision of minimal support. So, maybe let us say the, just you provide the shotcrete layer and maybe that will serve the purpose. So, the question now comes here that what about these three types of instability and how to tackle with them?

Then, we need to carry out the rock strength test to determine the rock fracture criterion. If you recall we discussed about some of the failure criterion, also so all those things will fall under this category. Then, we need to carry out the stress analysis of proposed excavation layout to check on the extent of potential rock fracture. Now the question comes whether the rock fracture can be minimized or eliminated by the change of excavation layout?

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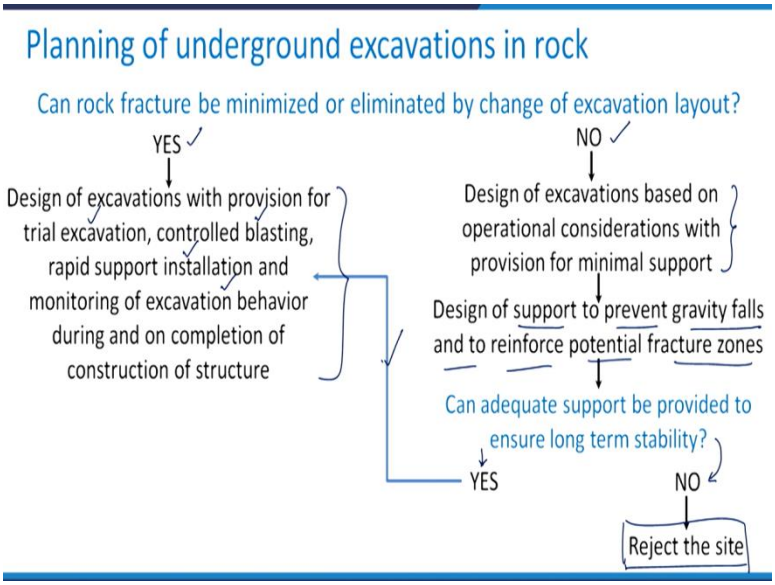

So, the answer to this question, again it is there can be 2 answers whether, it can be done or whether it cannot be done. Now, if this can be done then what we do is again, we go for the systematic step for the design of excavation having the provision for trial excavation, then controlled blasting to have minimum disturbance to the rock mass. Then, quick support installation and after that continuous monitoring of the excavation behavior during and after the completion of the construction.

In case, if the rock fracture cannot be minimized by the change of the excavation layout, then here, we need to design the excavation based on the operational consideration with the provision of minimal support. So, for that we need to design the support to prevent the gravity force, and also to, reinforce potential fracture zones. Now again, the question comes whether the adequate support can be provided to ensure the long-term stability?

If yes, then again, I will go to this path or I will follow this path and go ahead with the systematic approach for the design of excavation, and if we are not able to ensure the long-term stability, then we have no choice but to reject the site. So, this is how the planning of underground excavations is done, in case, if you have the instability due to excessively high rock stresses.

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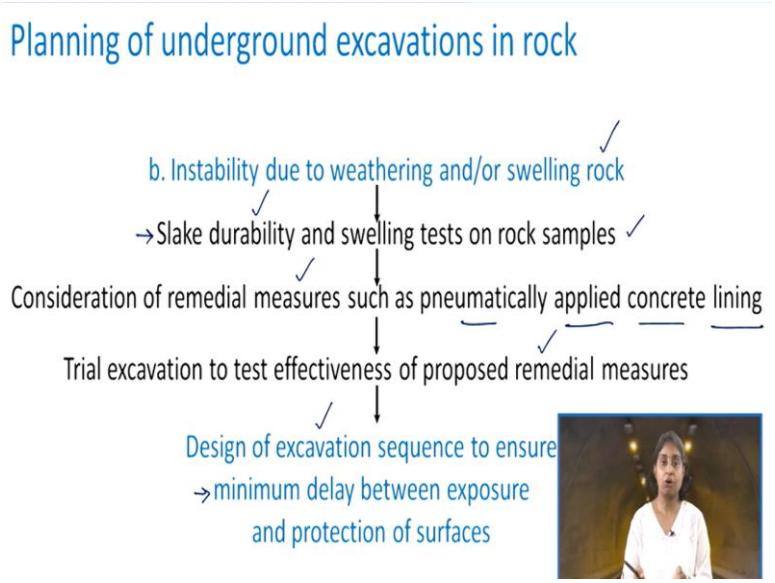

Now, coming to the next category of the instability which I mentioned to you were due to weathering or the swelling ground condition. So, in this case what we do is? We carry out the slake durability test and swelling test on rock samples. This Slake durability test, gives us the idea about the resistance of the rock or rock mass to weathering and by conducting these swelling tests,we can find out the swelling pressure, so that also gives us the idea about the characteristic related to the swelling ground condition.

Now, in this case we need to consider the remedial measures, such as pneumatically applied concrete lining. Then the trial excavation is done to test the effectiveness of proposed remedial measure, and subsequently we go for the design of excavation sequence, to ensure the minimum delay between the exposure and protection of surfaces. That means that, there should be minimum time duration between the excavation whether it is blasting, or some other method, and the installation of the support that is, protection of surfaces.

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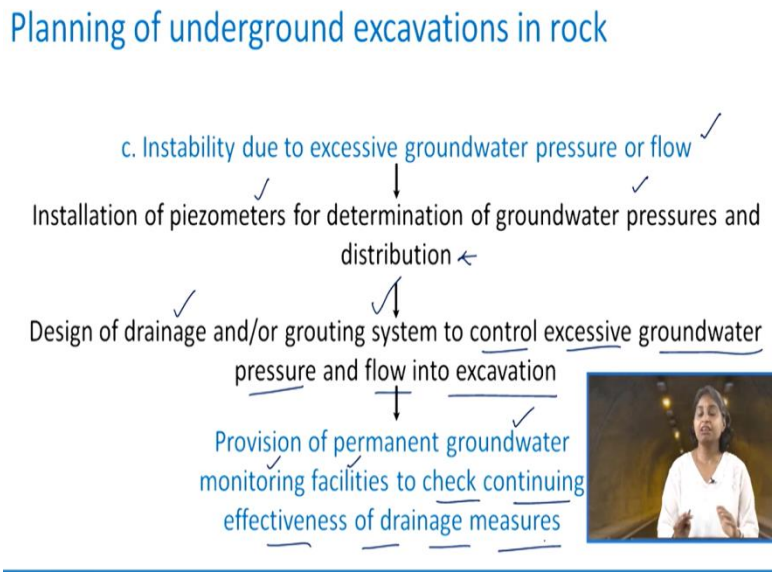

Now, coming to the third type of instability, which is, due to the excessive groundwater pressure or groundwater flow. So, what we need to do is we need to install the Piezometers for determination of ground water pressures and its distribution. Then, we need to have the proper design of drainage, or and grouting system to control excessive groundwater pressure and flow into the excavation.

This includes the provision of permanent groundwater monitoring facilities to check continuing effectiveness of drainage measures. So, you see that if we provide proper drainage measures, proper design of drainage measures, then we can handle the instability due to excessive groundwater pressure or groundwater flow. So, this was all about the planning of underground excavations in rocks.

So, you saw that there are various ways that the instability can be there, so we have to take the decision whether we can go ahead with the design and analysis of the underground excavation considering a particular layout. Or if, by changing the layout or the orientation if we can, if we cannot sort out those instability issues then in that case, we need to reject the site.

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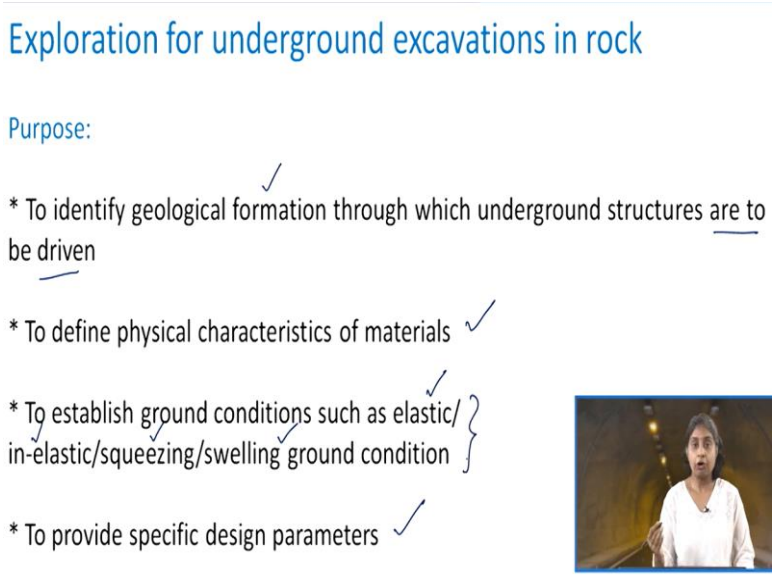

Now, coming to the second aspect related to the underground excavations in rocks that includes the exploration. First of all, what is the purpose of the exploration? The first purpose is to identify the geological formations through which the underground structures are to be driven.

Then, we need to define the physical characteristics of the materials then need to establish the ground conditions such as elastic, inelastic, squeezing or it is swelling ground condition, and then, finally to decide and provide the specific design parameters based upon what is the ground condition? Accordingly, you will have the respective design parameters.

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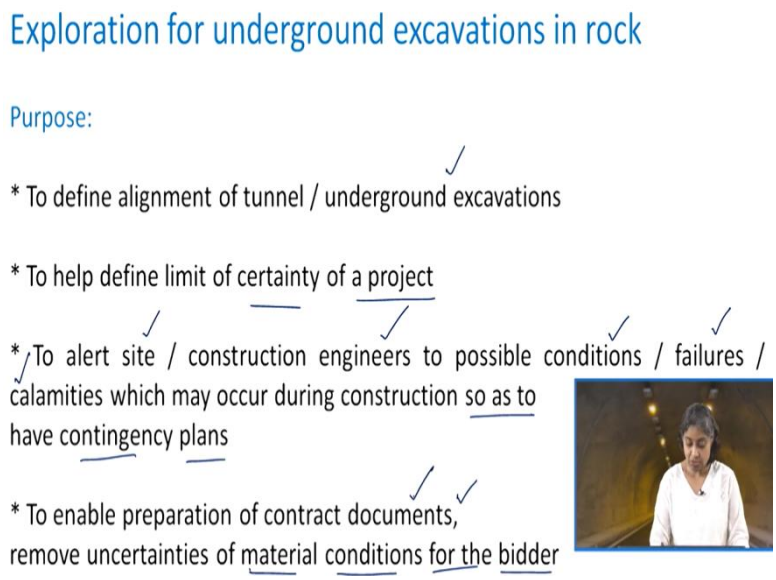

We need to decide, or define the alignment of the tunnel or the underground excavation it can be caverns, shafts and it or it can be tunnels. Then, we need to get the help to define limit of certainty of a project, see rock mass and rocks they are natural occurring material and a lot of uncertainty is involved. There so we need to find out that, what is the limit of certainty corresponding to any particular project?

Then the next purpose is to alert the site or construction engineers to possible conditions or failures or calamities which may occur during construction. So, as to have the contingency plans sometimes, let us say the exploration program is really very good, but still such surprises can be there at the site. Now to enable the preparation of contract documents, one needs to remove the uncertainty of material conditions for the bidder. So, this is also one of the purposes for the exploration of underground excavations in rock.

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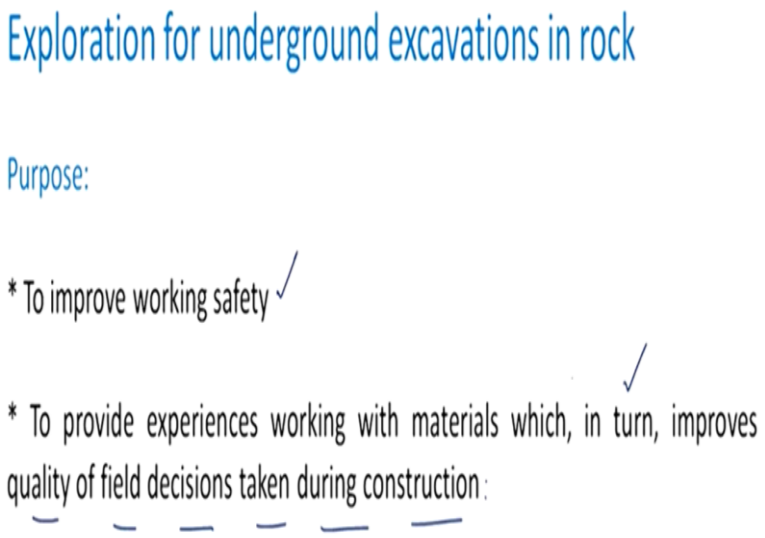

The next one, is to improve the working safety and to provide the experience working with materials, which in turn improves the quality of field decisions taken during the construction. Please remember, a well-explorated site is always better in order to finish the work at the site in time. So, it may happen that during the planning and exploration stage you think that it is too much of expense, but then it gives you lot of confidence.

So, it is better to spend earlier rather than repenting later, in case if you come across any of that surprise element at the site**.**

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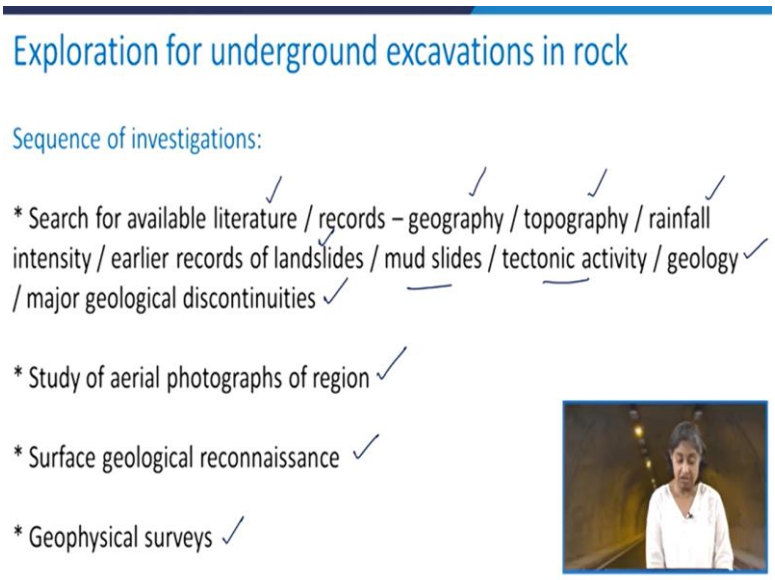

Now, the sequence of investigations include that, first of all we need to search for the available literature. We need to see the records related to geography, topography maybe the rainfall intensity. Then, if there is any earlier record of landslide at any particular site or mudslides or any tectonic activity or if there is any occurrence of geological or if there is any occurrence of major geological discontinuities.

Then, we need to study the aerial photographs of the region then surface geological reconnaissance is equally important and geophysical surveys are also helpful to do away with various uncertainties, which are involved with reference to exploration program.

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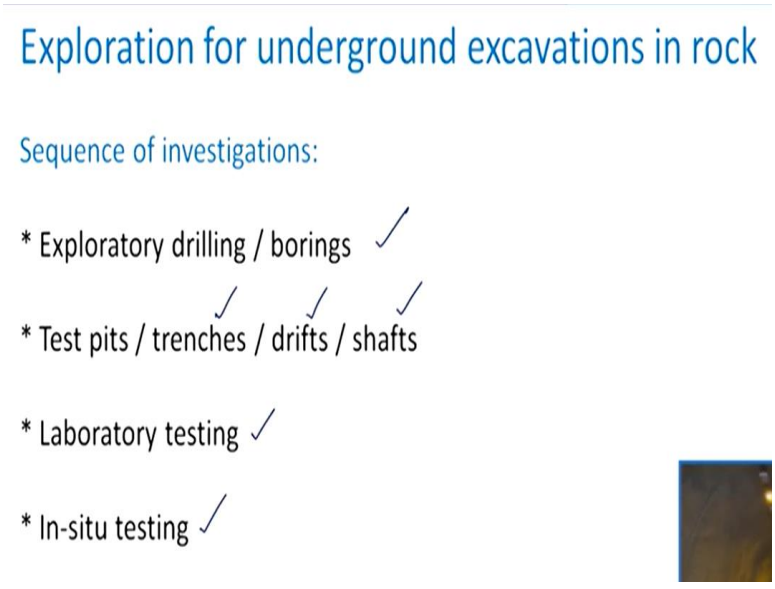

Then, one needs to go for the exploratory drilling or borings, test pits, trenches, drift, shafts all these things. I have already discussed with you, various definition about drift shafts, caverns, etc. Then, we can carry the samples to the lab and prepare the specimen, carry out the lab test. Then, some in-situ tests are also there to obtain the in-situ stresses and modulus of deformation.

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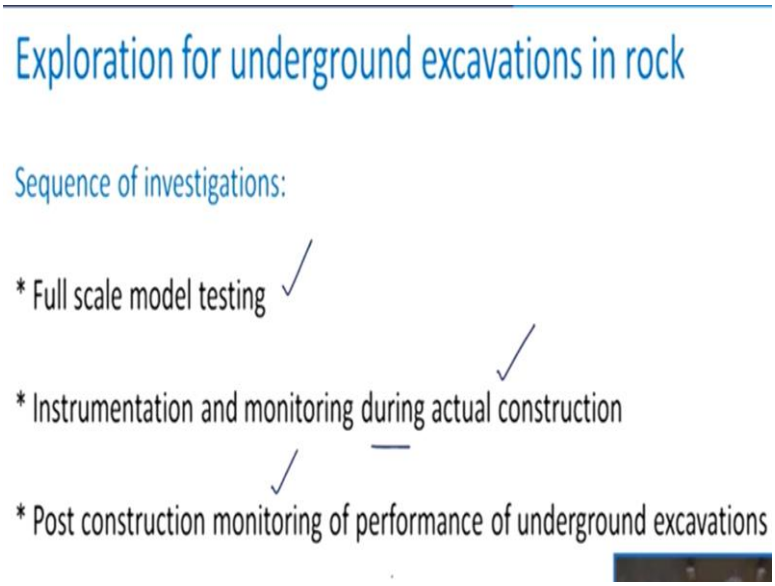

Now, one can go for the full-scale model testing then the instrumentation and monitoring during actual construction, and also the post-construction monitoring of performance of underground excavations is also helpful as far as the working of that underground excavation is a concerned.

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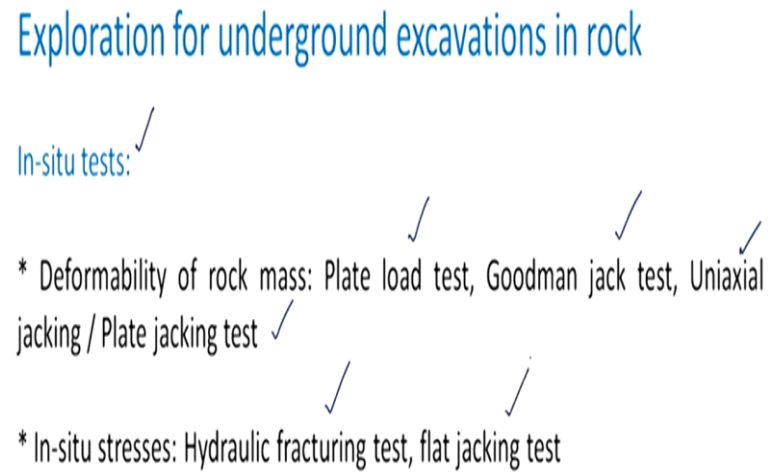

Coming to some of the in-situ test, so right now we are not going to discuss these in detail we will do this later in this course, but for the continuity I have listed some of these tests here.

So, in-situ tests, these involve with, reference to deformability of the rock mass the tests which are there, these are plate load tests, Goodman Jack test, uni-axial jacking or plate jacking tests. Then, we have the in-situ stresses that include hydraulic fracturing test and flat jacking tests.

So today we learned about some aspects related to planning of an exploration for underground excavations in rocks. I mentioned to you, that when can we go ahead with the site or when we need to reject the site. And then, we saw that what all are the various steps that one needs to take up, as far as the exploration is concerned. So, in the next class we will learn about some of the failure mechanism of the underground excavations in rocks, thank you very much.