Underground Space Technology
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Lecture – 51
Methods of Tunnel Excavation Various Support Systems Shotcrete

Hello everyone, In the previous class we saw that, how the method can be applied for the elastoplastic analysis of the rock mass tunnel support interaction phenomenon and we saw with the help of the three examples that, how we can approach to such type of problems. So, today we will start the next chapter dealing with the methods of tunnel excavation and various support systems.

So, today we will take up one of the support system, which is the shotcrete. Now for many classes you have been learning or you have been hearing about the terms like drilling and blasting, benching and heading and then shotcrete, rock bolts etcetera. So, all those terms we will learn these things in some of the few classes now.

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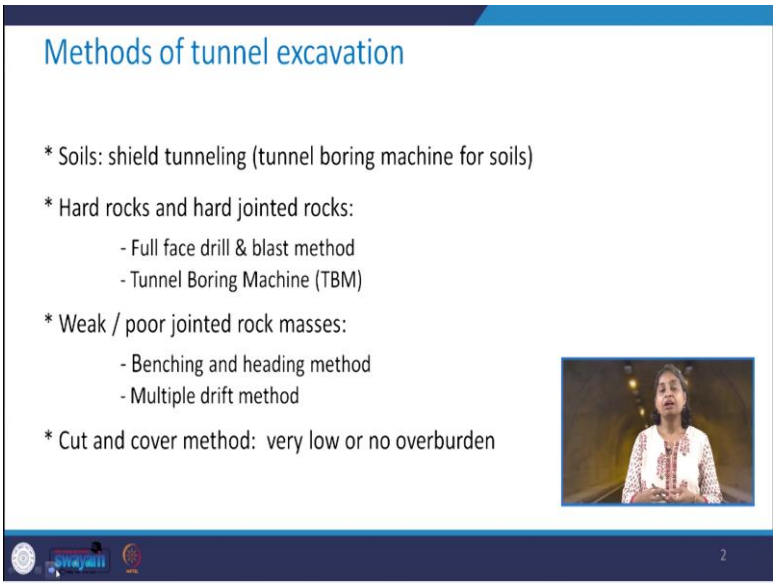

Now as far as the methods of tunnel excavations are concerned, the soils, we use shield tunneling there the tunnel boring machine is there especially dedicated to soils. In case of the hard rocks or hard jointed rocks, we go ahead with the full-face drill and blast method or the tunnel boring machine. If you recall, in some of the earlier classes I mentioned to you some details about the tunnel boring machine along with some of the pictorial views.

Then, we have for poor or weak jointed rock mass, there are methods like benching and heading method and multiple drift method which are more suitable. We have cut and cover method wherever you have, very low or almost low overburden on the excavation.

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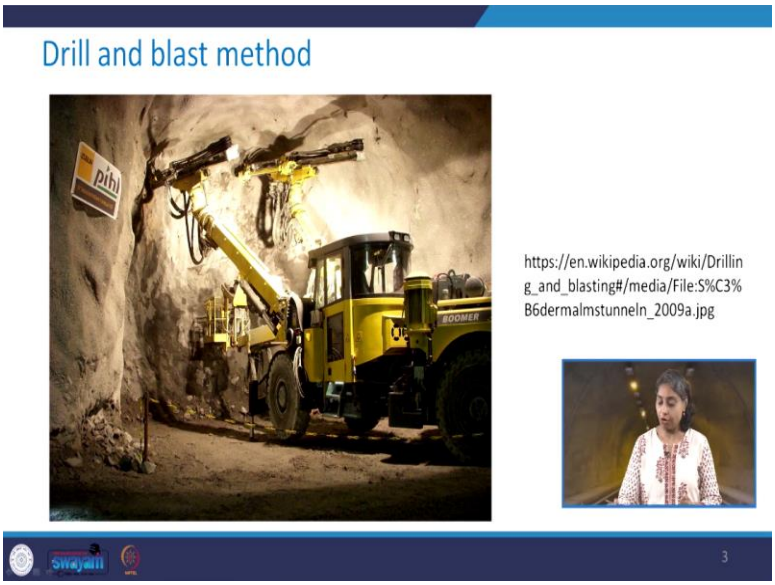

So, let us take them one by one. So, first we focus on the drill and blast method. So, here is a picture which has been taken from this source, there you can see that the rigs are working to make the holes in the rock mass. So, what all are the various steps in the drill and blast method let us try to take a look.

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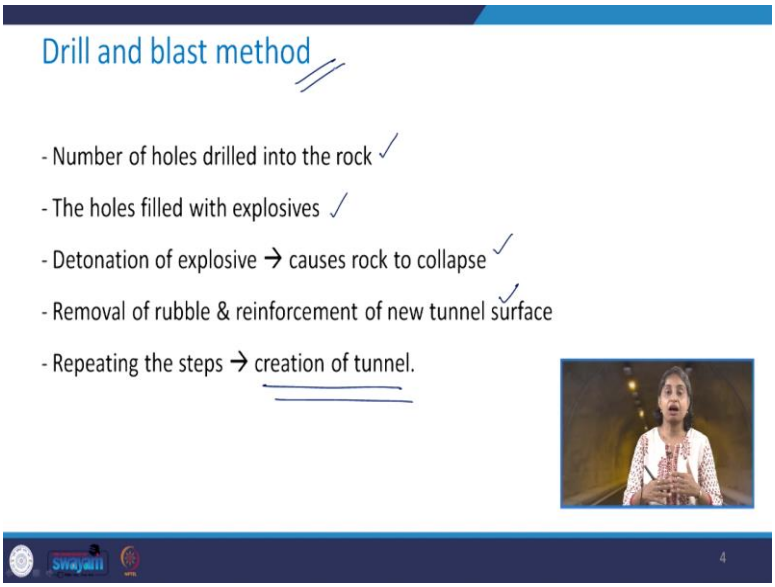

So, first of all in drill and blast method number of holes are drilled into the rock. What should be the length, what should be the diameter all those things can be designed and when these things are designed so we call this as controlled blasting. Once you have these holes which

are drilled into the rock, once these are filled with explosive then the detonation of this explosive takes place, so what happens because of that the blast takes place inside the rock mass, so that causes the rock to collapse.

Once this is collapsed, so, what will happen there is going to be the small fragments because of this blasting phenomena and there will be the lose material. So, we need to remove that rubber and reinforcement of the new tunnel surface should also be done depending upon what is a standup time and then we keep repeating these steps which are listed here, and slowly the result is the creation of the tunnel.

So, this is how the drill and blast method takes place. So, as the name suggest, first we drill some number of holes into the rock then we charge them with the help of explosive then the detonation of the explosive takes place. So, the rock collapse, and then the removal of the rubber is done followed by the reinforcement of the new tunnel surface, and these steps are repeated to create the tunnel.

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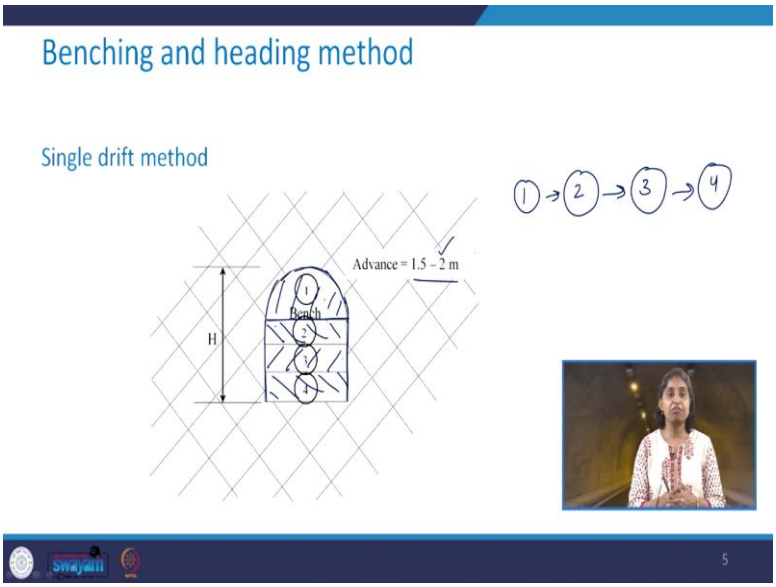

So, the next method is benching and heading method. In this, again we have two categories one is the single drift method and the second one is the multiple drift method. Now, let us say that there is an excavation, which is shown like this as is here in this figure. This is the excavation which is to be made. So, in single drift method you see that you create a bench which is equal to the width of the excavation.

So, we create a horizontal bench up to the length of the excavation perpendicular to the plane of screen. The advance which is made, or the heading that is used in one go is 1.5 to 2 meter then, once this portion is removed that means that the removal sequence is going to be 1 and then, the second portion followed by the third one and the fourth one. So, once this portion is removed then we lower this bench maybe this second part.

And then, the third one followed by the fourth one. So, here, in this case, you see why this is called as a single drift method means here, we have only one bench which is made throughout the length of the excavation, but in case, if we have very poor rock mass then this type of the method may not work. In that case, then we have to go for the multiple drift method. So, before I discuss with you, multiple drift method, first let us try to take a look at some of the significant feature of this single drift method.

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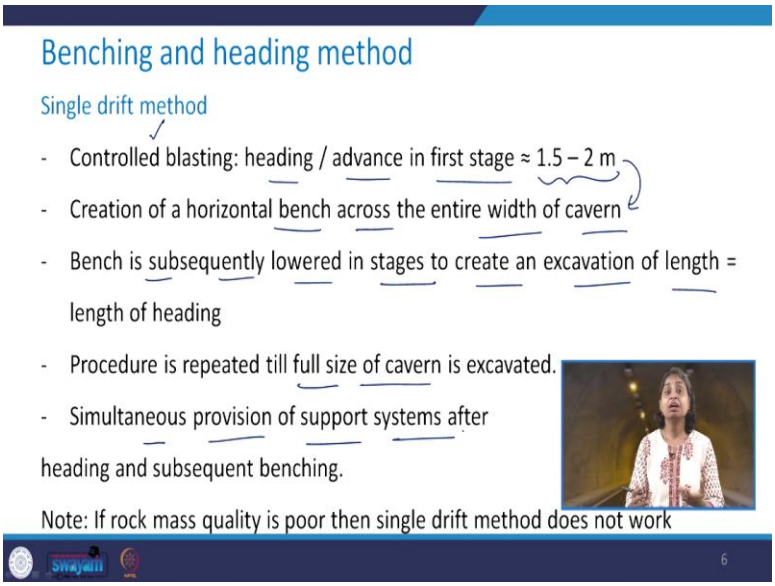

So, here we employ the controlled blasting in such a way that heading and advance in the first stage is approximately 1.5 to 2 meters. This will help us in creation of a horizontal bench across the entire width of the cavern. So, the bench is there across the entire width of the cavern. This bench is then subsequently lowered in stages to create an excavation of length which is equal to the length of the heading.

This means the dimension perpendicular to the plane of the screen. So, this complete procedure is repeated till we excavate the full size of the cavern. Now, what we do is the moment we excavate we keep on providing the support system simultaneously. So, there

should be the simultaneous provision of the support systems after the heading and then the subsequent benching.

The question is if the rock mass quality is poor then what will happen? then this single drift method will not work. So, can we again use benching and heading method for the excavation? The answer is yes.

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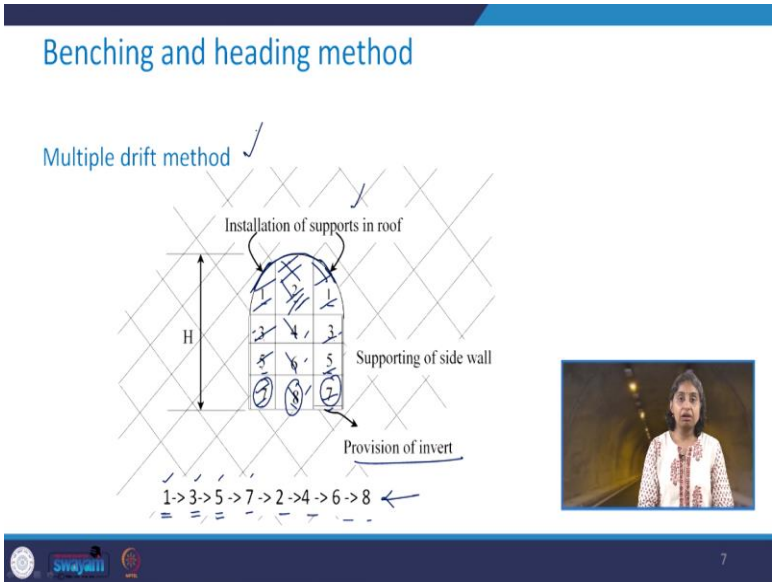

But then we need to go for the multiple drift method. Now, you see that here numbers are written some here throughout the excavation. So, you see 1, 1 then we have 2, 3 on both sides 4, 5 on both the sides again 6, 7 and 8. So, you can have the different sequence of this excavation like in this case one can go for the excavation in the following sequence like first you remove the areas 1 then 3, then 5, 7 and then you go ahead with 2, 4, 6 and 8.

So, what will happen if we remove 1, 3, 5 and 7 so what will happen this will be removed along with this one. So, only a column here which is comprising of this particular area this will be left and then once these two-side excavation has been made, we can immediately support the sidewall, and then maybe we can start the excavation from the roof again. So, this is how the multiple drift method works.

So, you see that here the benching is done not across the complete width of the excavation, but in parts. So, when you do it in part and install the support system simultaneously what happens is the part which has been excavated, now it is supported and then you can carry on

the remaining portion for the excavation. Now, in this case it is not necessary that you follow this order of the excavation, or this sequence of excavation as I just now explained.

Somebody can go for maybe removal of 1, then followed by 2, then, provide the support in the roof portion, and then maybe you know keep on excavating the third portion and then the fourth and keep on providing the support. So, whatever that we excavate to the best extent possible we keep providing the support system simultaneously. So, in case, if we go for this sequence as it has been mentioned here.

First, what we will do? we excavate it and then we provide the support system to be sidewalls and, then once you remove this second portion then you provide the complete installation of the support system in the roof. After the removal of this, 7 portion, maybe you can provide the invert here and, once you remove this 8th portion then you will be having the complete excavation ready. So, this is what is called as multiple drift method.

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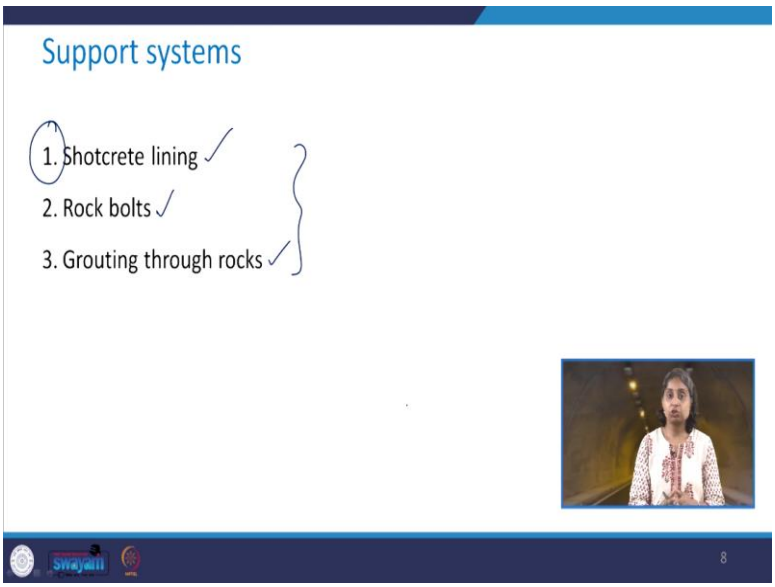

Coming to various support systems, so we have discussed this, that we may have the shotcrete lining, rock bolts, or steel sets or we can go for the grouting through rocks. So, as far as this course is concerned, we will be focusing on these three which is the shotcrete lining, rock bolts and grouting through rocks. So, today and in the next class we will take up the first type of the support system which is the shotcrete lining. We will learn about various aspects related to the shotcrete lining.

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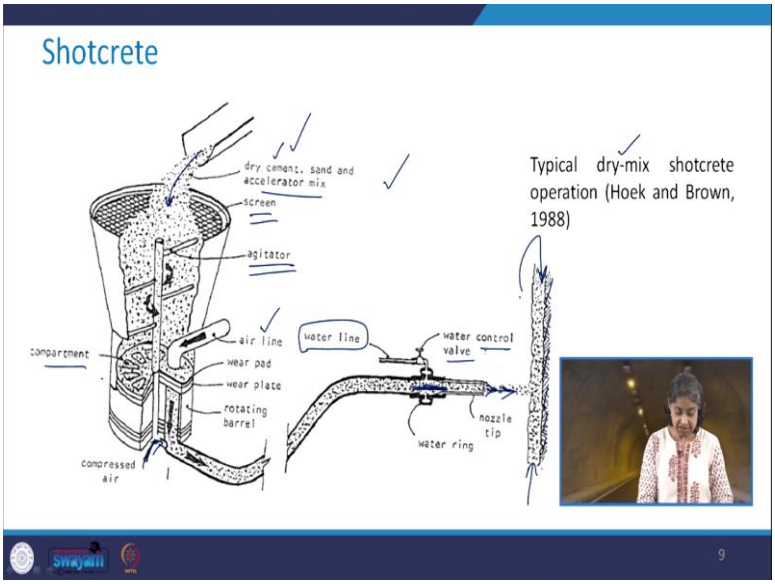

So, what exactly is shotcrete? how it is prepared? what exactly is the procedure? So, there are two types of typical shotcrete operation. One is the dry mix and another one is wet mix. We will see that, what exactly is the difference between the two, but how this is prepared this figure is self-explanatory. You see here that the dry cement sand and accelerator mix is fed from this place to this agitator.

Here that goes through this screen, it goes to the agitator there is the compartment where through this we pass the air through this compartment and, then we supply the compressed air here and see it goes to the end here there note that we have a water line and, then there is a control wall through which, you can control the amount of water which is to be fed to this dry mix of the cement, sand and the accelerator.

And we have the nozzle tip, through which the shotcrete comes out under the pressure and, you see that this is the surface of the rock mass and how the shotcrete layer is placed here on the rock mass surface. This is about the dry mix shotcrete operation.

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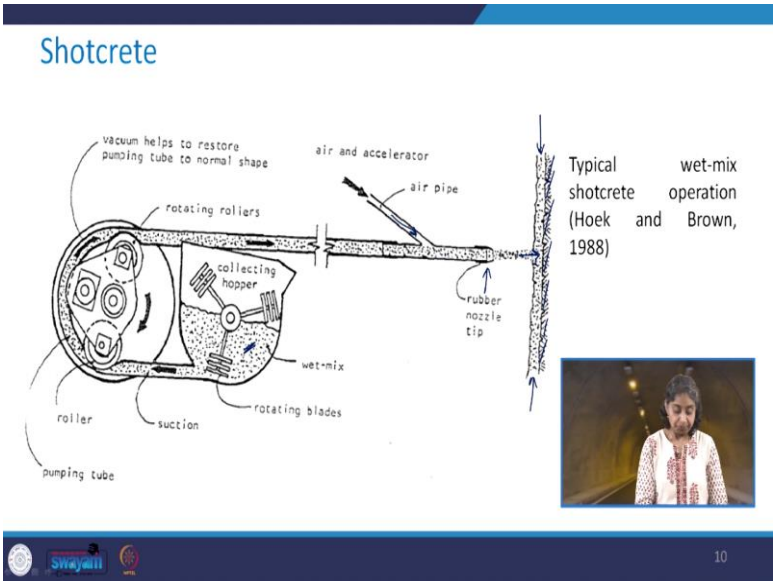

Let us take a look at the typical wet mix shotcrete operation. So, in this case, the difference is that earlier we were mixing the ingredients in the dry form, and just before the spraying of shotcrete we were mixing it with water, but in this case, it is little bit different here we have the wet mix ready. So, that means that the water is added while preparing the mix, and then simply it is transported.

And then this is the air pipe and, this is the rubber nozzle tip through which under pressure, this shotcrete is sprayed on the rock mass surface in this particular manner.

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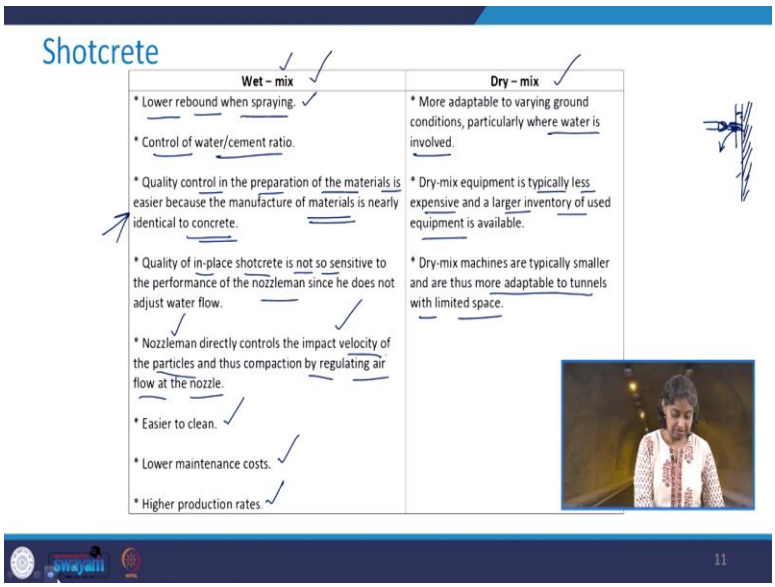

Let us understand, what is the difference between wet mix and the dry mix? As far as wet mix is concerned there is going to be the lower rebound when spraying. Now, what do we understand by this rebound? So, let us see this is the rock mass surface with the help of the

nozzle you are spraying the shotcrete. Now, what will happen depending upon the surface and the material here the shotcrete material will go it will stick to this particular surface.

And then, some portion will be rebound from this surface. So, that is what we call as the rebound. So, when we have the wet mix there is the lower rebound when we are spraying it. Since, we are mixing it with the water earlier when we are preparing the mix, so we have full control of the water-cement ratio. The quality control in the preparation of the material is easier in this case because, the manufacturing of the material is very near or identical to concrete.

Quality of in-place shotcrete is not really very sensitive to the performance of the nozzleman, since he does not have to add the water flow. While, in case of, the dry mix what happens is that this quality it depends upon the nozzleman performance because he has to control that how much of the water should be mixed before it is sprayed on the rock mass surface. The nozzleman directly controls the impact velocity of the particles.

And thus, compaction by regulating the airflow at the nozzle is there. The wet mix is easier to clean it has lower maintenance cost and high production rates. However, coming to the dry mix situation it is more adaptable to varying ground conditions particularly where there is a presence of water. The dry mix equipment is typically less expensive and larger inventory of used equipment is available.

The dry mix machines are typically smaller and therefore more adaptable to tunnels where the limited working space is available, but then, both of these they have their positive as well as negative points. So, here we have to take a call that based upon the situation that we have in the field one should adopt whether it is to be wet mix or dry mix.

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Now, this is a typical picture, where you can see a nozzleman spraying the shotcrete on the rock surface and, you see that a steel mesh is also laid. Now, what is the purpose of this steel mesh let us take a look.

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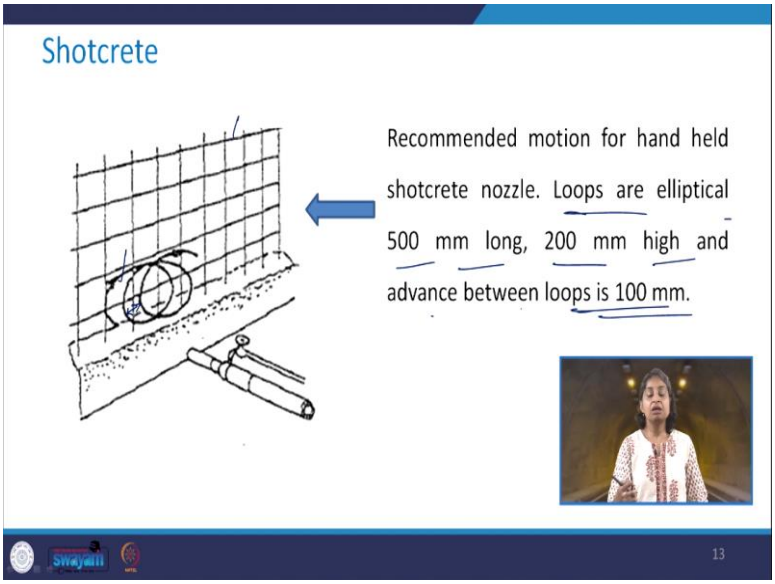

But, before that say this is the mesh and then this is the nozzle. So, the nozzleman has to make this kind of an operation or to have this elliptical motion, so that, the loops are elliptical which are 500 millimeter long, 200 millimeter high and advance between the two loops is 100 millimeter advance means this distance, the distance from one loop to the other loop. Although, these days machines are also available, but sometimes this manual operation of the shotcrete is also done.

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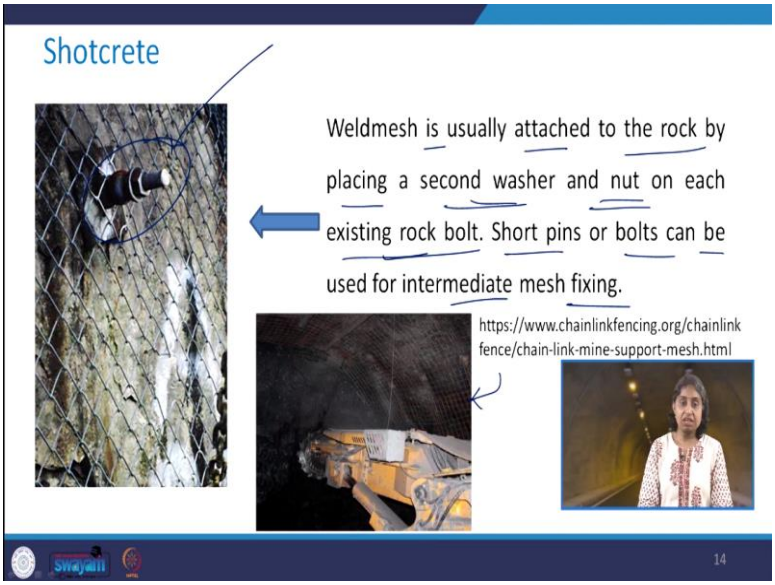

As I was mentioning that, usually a mesh is first attached to the rock surface before the laying of the shotcrete or spraying of the shotcrete. So, this weldmesh is usually attached to the rock by placing a second washer and nut on each existing rock bolt. So, let us say if you have to go for the combination of rock bolt and the shotcrete. So, this is how it looks like this is how. So, here you see that with the help of a second washer and, nut how the steel mesh is held at place to already existing rock bolt.

Then, you can have a shot pins or bolts also used for the intermediate mesh fixing. So, here this is what is the chain link fencing that is being shown, that is attached with the excavated surface.

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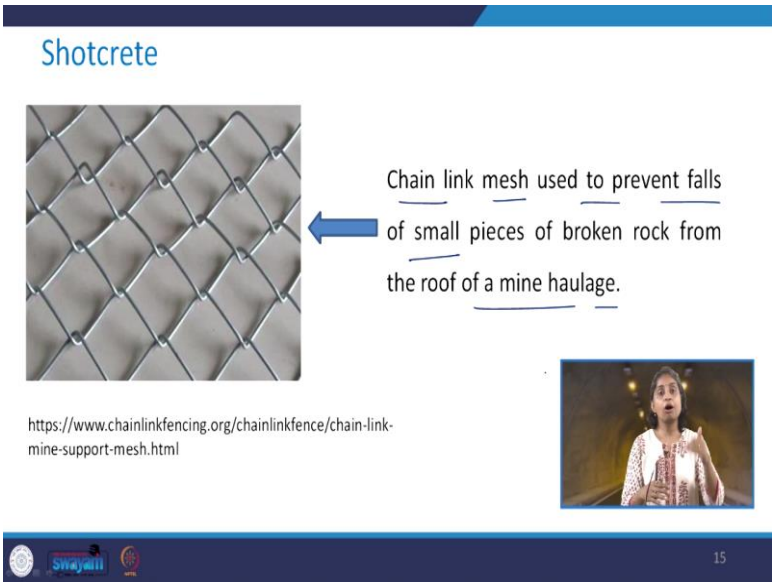

So, this is how it looks like the zoomed version of that. So, this is the chain link mesh which is used to prevent falls of small pieces of broken rock from the roof of mine haulage. So, what happens is immediately upon the excavation, you lay such type of chain link mesh. So, whatever is the broken rock mass pieces, it will not fall down inside the excavation. This mesh will hold it and, then once this mesh is fixed all along the excavation and, then you can spray the shotcrete.

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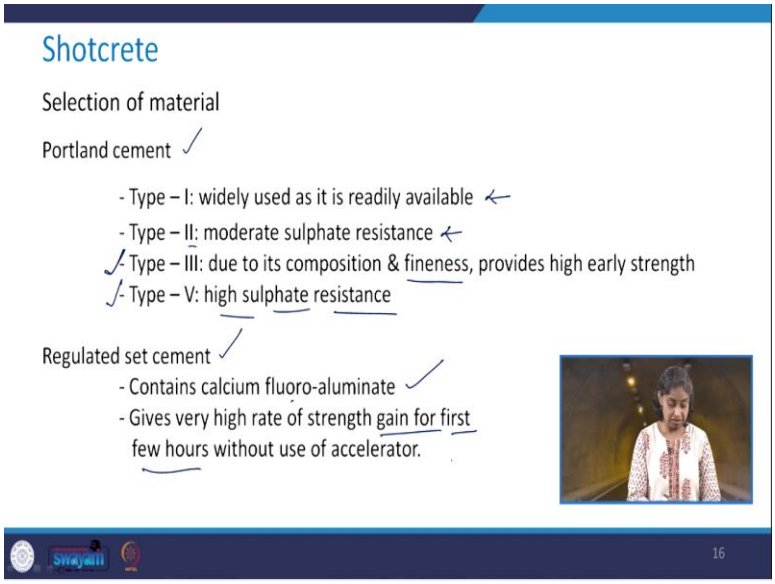

Coming to the selection of material for the preparation of shotcrete. So, you need to have the Portland cement. So, there are four types of the portland cement they can be used. The type 1 is widely used because it is readily available, but then in case if there are such requirement that need some special type of the portfolio cement, then you may choose the other type such as type 2 which has the moderate sulphate resistance.

We have the other one, which is type 3 because of its composition and the fineness this provides high early strength. So, in case if our requirement is that the stand-up time is low then maybe one can go for the type 3 type of the Portland cement. Coming to the next one, if the situation is such that, that you need high sulphate resistant portland cement, then, maybe you can go for type 5 portland cement for the preparation of shotcrete.

Then, we have few special regulated set cement. So, these contain calcium fluoro aluminate. This gives very high rate of strength gain for the first few hours without any use of the accelerator.

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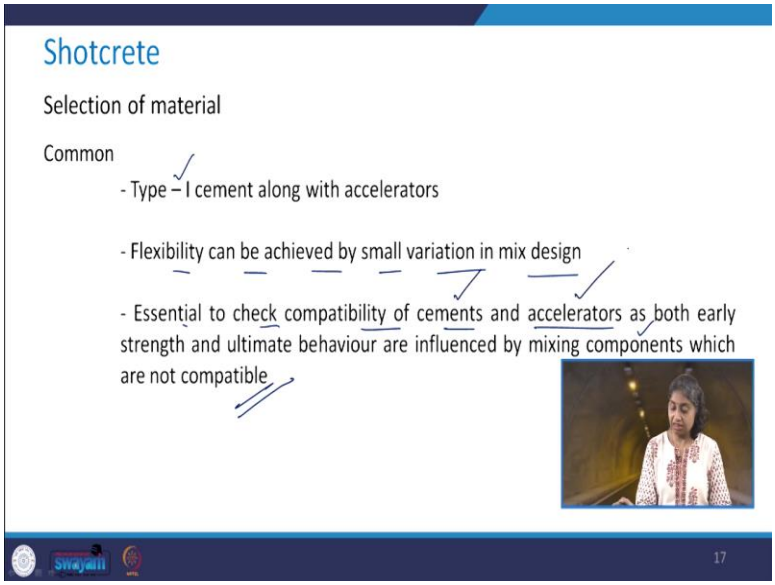

The common use is the type 1 cement along with the accelerators. Then flexibility can be achieved by small variation in mix design, how this is done that also we will learn. Essential to check the compatibility of cements and accelerator, as we need both the early strength and the ultimate strength. So, therefore compatibility of the cement and accelerator should be there because the early strength, as well as the ultimate strength both are influenced by mixing the components which are not compatible. So, we have to be careful about the compatibility of cements and the accelerators.

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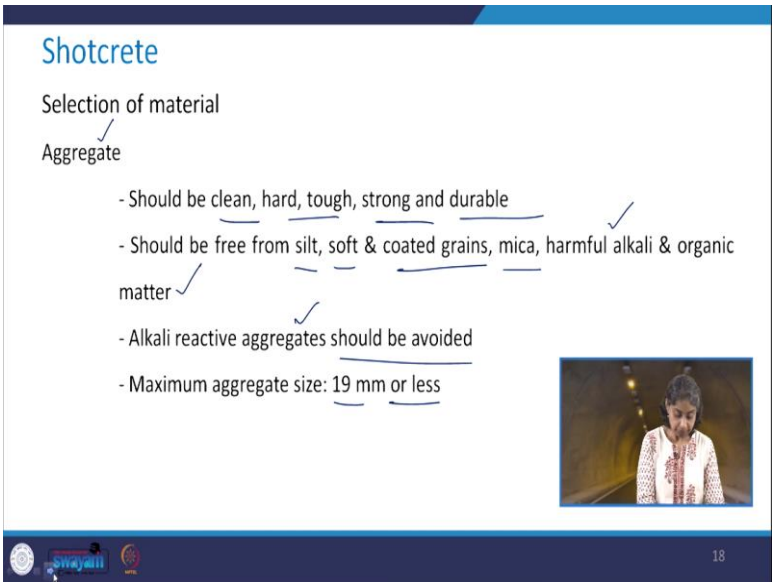

Then, coming to the next component of shotcrete as far as selection of material is concerned this is aggregate. It should be clean, hard, tough, strong and durable. These one should keep in mind. These should be free from silt, soft and coated grains, mica, harmful alkali and

organic matter then alkali reactive aggregates should always be avoided and, the maximum aggregate size that one should use should be 19 millimeter or less than that.

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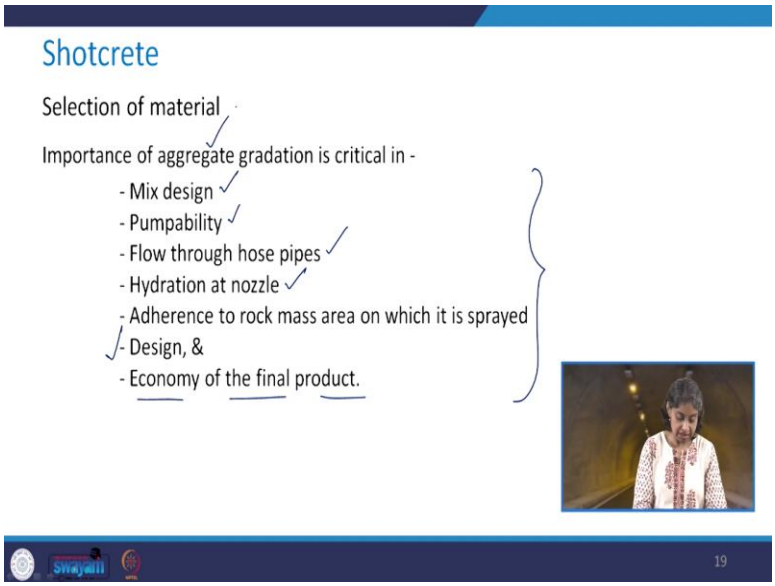

What is the importance of aggregate gradation? So, this is critical in the mix design, pumpability, mix design of the shotcrete, then pumpability then flow through the hose pipes, hydration at nozzle when we spray on the rock surface, what is the adherence of it to the rock mass area, then this is also very critical in the design of the support system and ultimately the economy of the final product.

So, since it is extremely critical in all these factors one should be careful about the choice of aggregate gradation.

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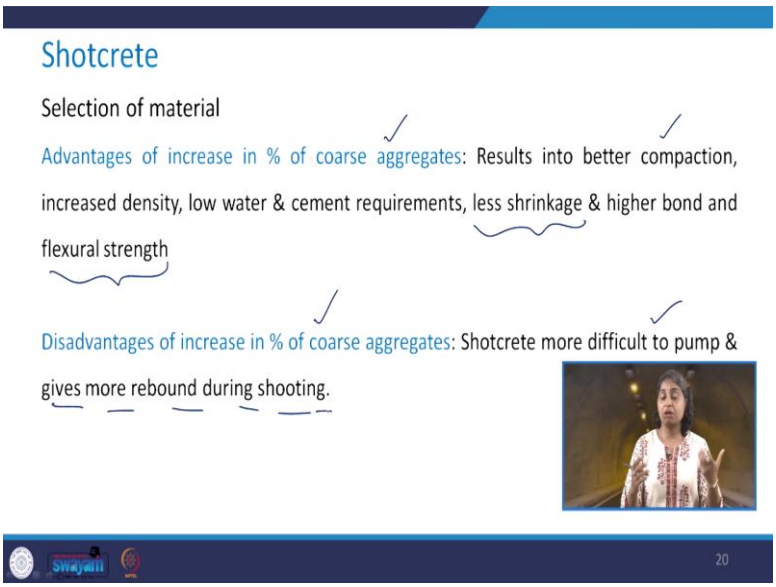

What are the advantages of increase in the percentage of coarse aggregates when you increase it? it results into better compaction, it results into the enhanced density and low water and cement requirement it results into less shrinkage, and the higher bond, and the flexural strength, but then, there are also some of the disadvantages which are associated with an increase in the percentage of the coarse aggregate.

Since, the shotcrete is more difficult to pump and it gives more rebound during the shooting, if it has the more percentage of the coarse aggregate. So, what we need to do is we need to design the proper percentage of the coarse aggregate which is to be mixed while selecting the material for the shotcrete because, if too much of the coarse aggregate is there then it becomes difficult to pump and also it will give more rebound. So, we will have more loss of the material during spraying or shooting of the shotcrete layer.

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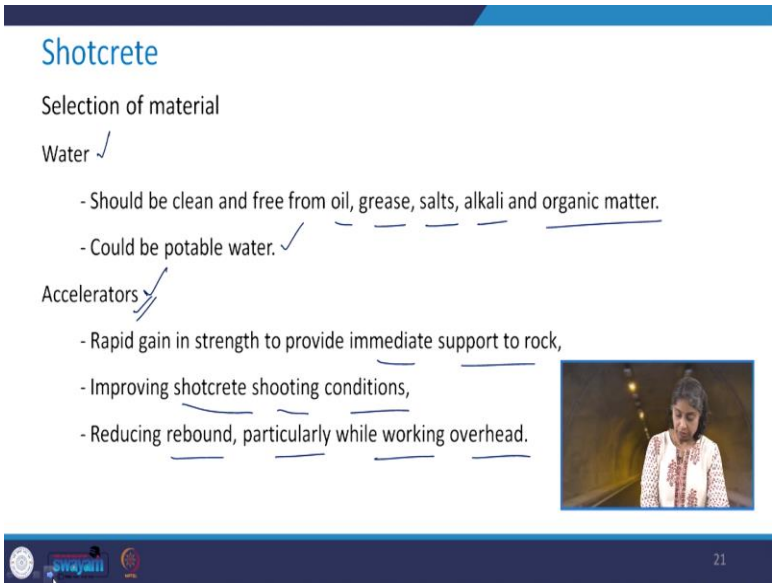

Coming to the next material which is water. So, it should be clean and it should be free from oil, grease, salts, alkali and the organic matter. The potable water can be used while preparing the shotcrete then the next material which is to be added is the accelerators. There is the rapid gain in the strength to provide the immediate support to rock. So, we have the cement, sand, and the coarse aggregate along with the water plus we add the accelerator.

The reason is that, if one needs to have the rapid gain in the strength to have the immediate support to the excavated surface then, one should go for the addition of the accelerators. Then, addition of the accelerators also improves the shotcrete shooting conditions. These

reduce rebound particularly while working overhead. Overhead means, is the roof portion or if a person is there, so whatever is there above his or her height.

So, as far as the sidewalls are concerned if it is the lower portion of the sidewall then, of course, the rebound will not be that much even in the general condition, but when working overhead this addition of the accelerator reduces the rebound.

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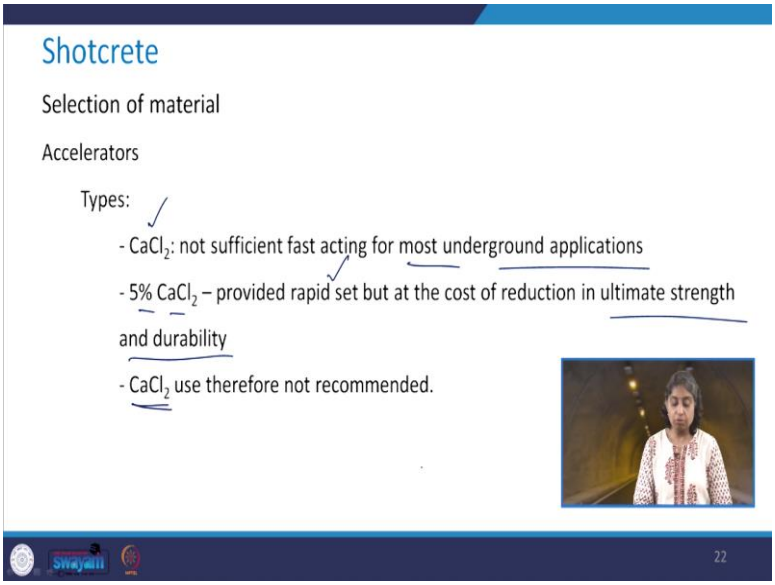

What types of the accelerators that are available? So, the first type is $CaCl_2$. It is not sufficient fast acting for most of the underground applications. So, the 5% of $CaCl_2$, it provided the rapid set, but at the cost of reduction in ultimate strength and durability. So, here you know that we have to take a call that what is more important for us whether we be need the rapid setting or we can have a compromise towards the reduction in the ultimate strength and durability, which may not be acceptable in most of the projects and therefore, the use of $CaCl_2$ is not recommended that often.

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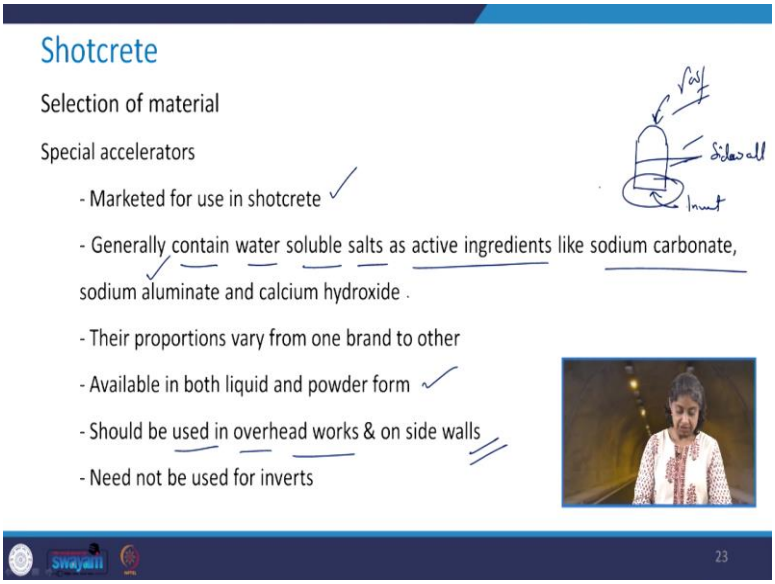

There are various special accelerators which are marketed for use in shotcrete. These, generally contain water-soluble salts as active ingredients like sodium carbonate, sodium aluminate, and calcium hydroxide. Their proportions may vary from one brand to the other and these are also available in liquid as well as the powder form. These should be used in overhead works and on the sidewalls and need not be to be used for inverts.

So, if you recall that if we have this type of let us say the excavation. So, this is basically the roof portion these are the side walls and this is the invert portion. So, what the guideline say that, these special accelerators, it should be used in overhead works that is maybe roof or the sidewalls and also on the sidewalls, but then need not to be used for inverts.

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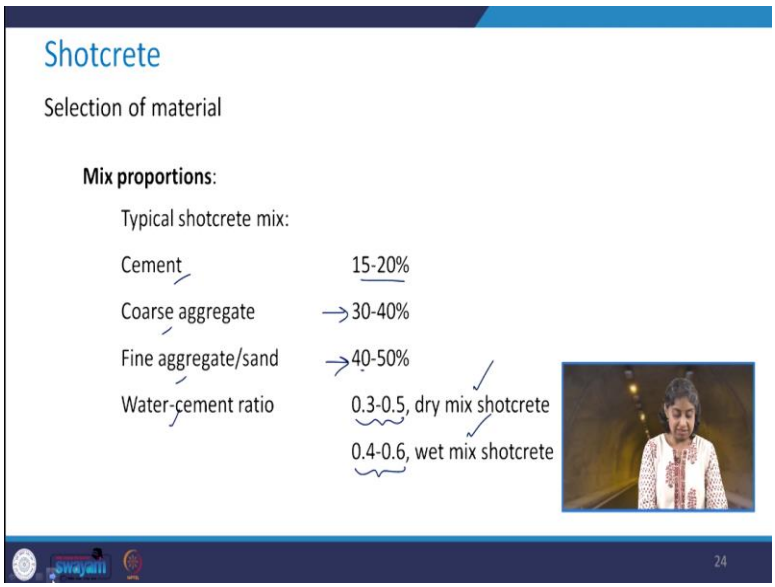

Coming to the mix proportions. So, typical shotcrete mix is having cement, coarse aggregate, fine aggregate, and the water-cement ratio. So, this is 15% to 20% coarse aggregate should be 30% to 40%, fine aggregate should be 40% to 50% and the water-cement ratio should be between 0.3 to 0.5 in case of the dry mix shotcrete and, in case of the wet mix shotcrete, it should be 0.4 to 0.6. So, this is about the mix proportions.

In the next class, we will learn about some aspects related to admixtures, which should be added to the shotcrete to have its enhanced effect. So, thank you so much.