Rock Engineering
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Lecture - 55
Rock Slope Stabilization

Hello, everyone. In the previous class, we saw that how using the limit equilibrium method. We can analyze the rock slope, which is undergoing the toppling failure. Today, we will learn about the stabilization of rock slopes. We have seen that the rock slopes may fail in either plane failure mode or wedge failure or circular failure or toppling failure. In case if the analysis gives us the result that the slope is unstable, how to stabilize that slope and make improvement in the value of the factor of safety so, that the slope becomes stable.

All those techniques, we will learn in brief today. So, these rock slope should remain stable at least up to the design life of the specific project. Say, if one needs to go for a road construction and depending upon what is the life of that road, which has been made by cutting the slope, that slope also should be stable up to that much of the design life. Now, the possibility during the site selection to have stable excavated rock slope without any major treatment or stabilization, maybe there, provided that the orientation of joint or bedding planes is properly assessed before the site selection.

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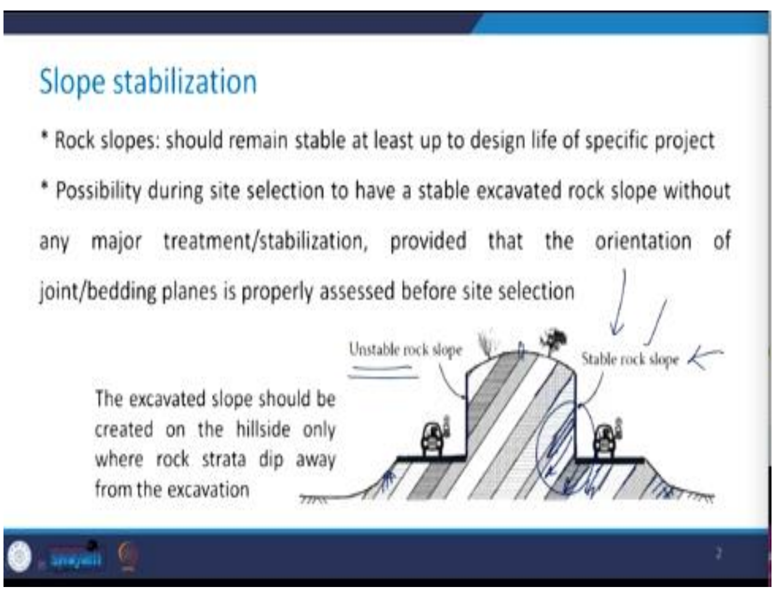

Now, take a look at this picture. It beautifully defines this particular condition. You can see that this is a slope in which the planes are dipping in this direction and the 2 cases have been shown. In one case, the slope has been cut in this particular manner here and in another case, it has been cut in this manner on the other side. Now, this is said to be stable rock slope however, the other side is the unstable rock slope.

So, why? Why this is unstable? Because the rocks strata is dipping towards this excavation. So, the excavated slope should be created on the hillside only where the rocks strata dip away from the excavation. Like in this case on this particular side, it is dipping away from the excavation. So, it is stable. However, in this case, it is the opposite situation and that makes this rock slope as unstable rock slope.

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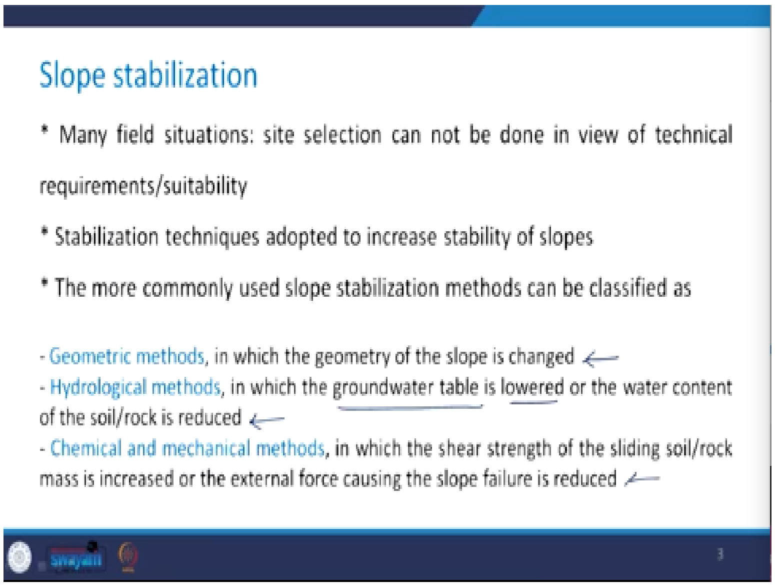

But most of the time in many field situations, this site selection cannot be done in view of the technical requirements or the suitability. Therefore, stabilization techniques should be adopted in order to increase the stability of slopes. The more commonly used slope stabilization methods can be classified under 3 categories. The first category relates to the geometric methods in which the geometry of the slope is changed. So, that the changed geometry slope is stable than the earlier one.

The second category belongs to the hydrological method in which the groundwater table is lowered or the water content of the soil or the rock is reduced. You know that the presence of water, it reduces the strength of the material. So, in case if this can be altered, then it may fall under one of the category of these slope stabilization technique. The third one has chemical and mechanical methods in which the shear strength of the sliding soil or rock mass is increased or the external force causing the slope failure is reduced by some means.

So, basically, these are the three methods, which can be commonly adopted for the slope stabilization. Coming to the first method which is the geometric methods. This includes slope flattening, removal of the part of the soil or rock or the load from the top of the slope. Then construction of pressure berms at the toe, terracing, replacement of these slipped material by free draining material and re-compaction of slip debris. So, all these methods, they fall under this category of the geometric methods.

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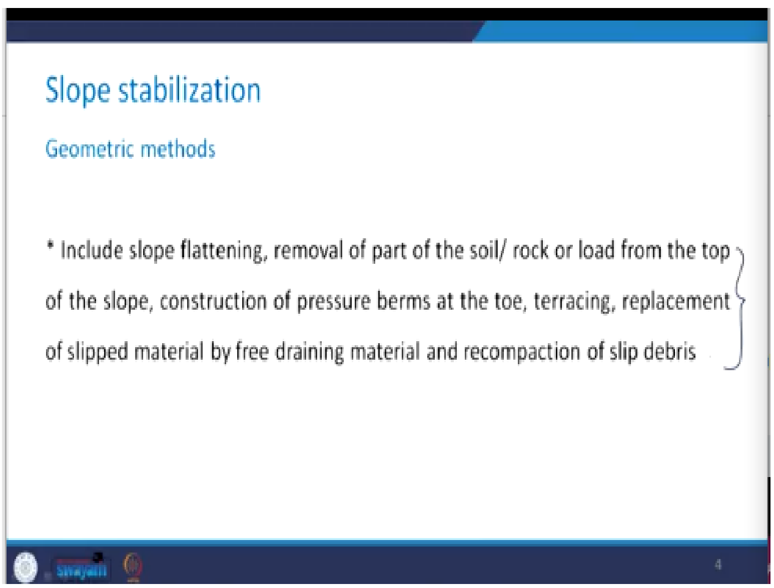

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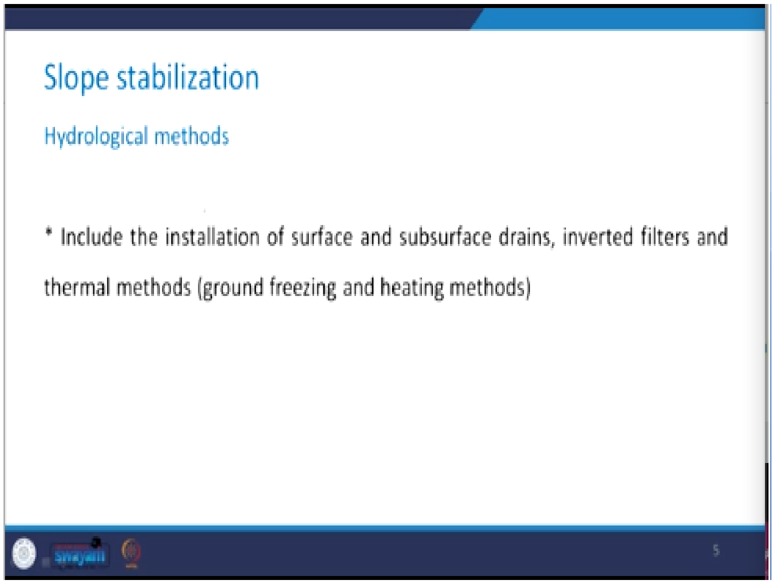

The second one includes the installation of surface and subsurface drains and these are called as the hydrological methods. Inverted filters can also be provided and the thermal methods such as ground freezing and heating methods are also used in order to control the groundwater table in the field. Then, the third method is the chemical and mechanical methods, which is very, very important and most commonly adopted.

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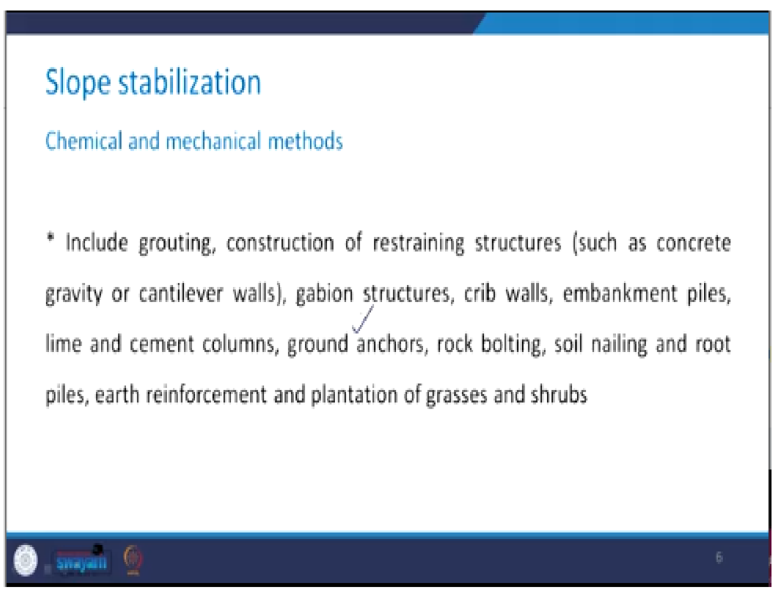

These include grouting, construction of restraining structures such as concrete gravity or the cantilever walls, gabion structures, crib walls, embankment piles, lime and cement columns, ground anchors, rock bolting, soil nailing and root piles, earth reinforcement and plantation of grasses and shrubs.

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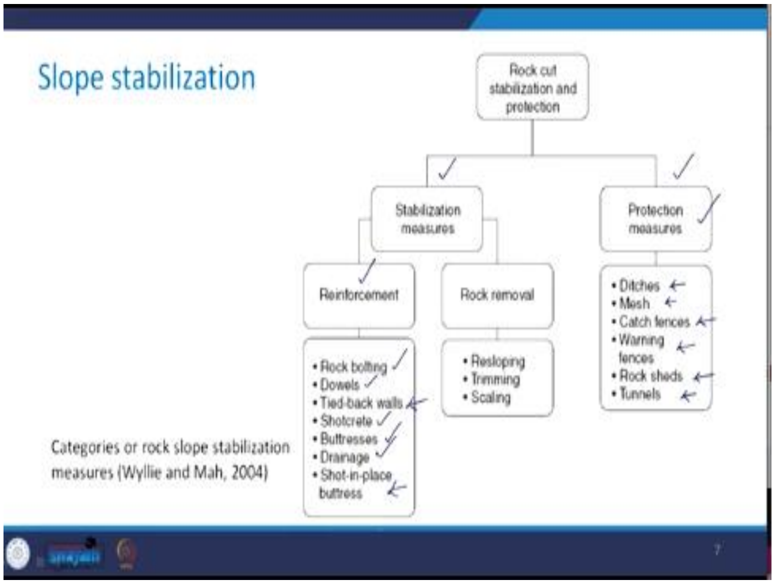

Let us try to take a look here in a summarized fashion that what all methods can be adopted for the rock slope stabilization under different categories. So, there are basically 2 branches of this tree. One deals with the stabilization measures. Another one with the protection measures. As far as the protection measures are concerned ditches, mesh, catch fences, warning fences, rock sheets and tunnels. They are used as the protection measures. Coming to the stabilization measure.

So, the first branch of this deals with the reinforcement of the slope and that can be done by rock bolting by providing the dowels or tied-back walls, shotcrete, buttresses, drainage, then shot in place buttress. We will discuss some of these in detail now. But before that, the other method which can be used for the stabilization purpose is the rock removal and this includes re-sloping, trimming or the scaling of the slope in order to make it more stable have larger value of the factor of safety.

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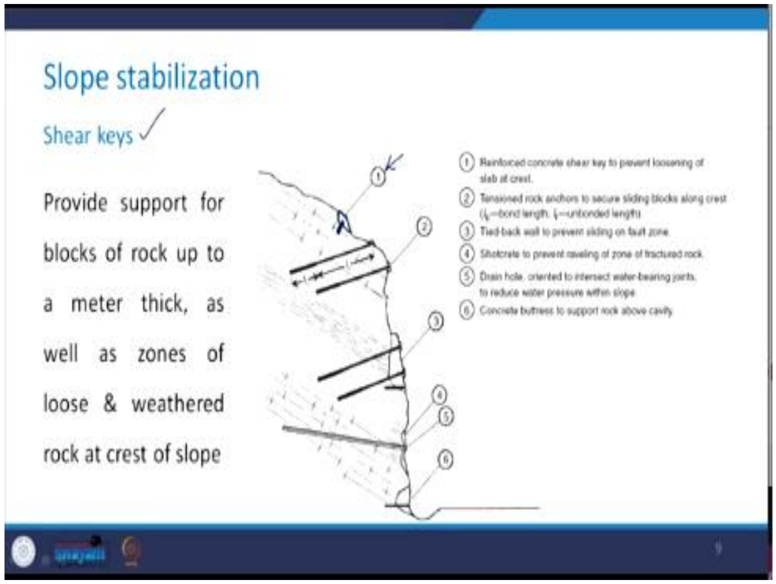

Now, this figure has some of the measures which can be adopted to reinforce the rock slope. Let us discuss these measures one by one. So, the common feature of all these measures, they are to minimize the relaxation and minimize the loosening of the rock mass that may take place as a result of the excavation. What happens once the relaxation is allowed to take place? There is going to be the loss of interlock between the blocks of rock and this leads to a significant reduction in the shear strength, which is not desired.

So, in order to minimize these relaxation and loosening of the rock mass, we can adopt any of these technique of these stabilization of these slope using the different types of reinforcement. So, the first type of reinforcement that I am going to discuss with you includes the shear key. Now, take a look here, this first measure that is what the shear key is. So, you can see here that this key has been plugged into the rock slope and here, this portion was which was unstable.

So, basically, what the shear key does is, it provides support for the blocks of the rock up to a meter thick as well as zone soft loose and weathered rock at the crest of the slope. So, you see that here this is at the crest of the slope and the shear key as a protection measure stabilization measure has been used. These are used where the support required is limited by the size of the blocks and to prevent raveling and loosening of closely fractured weak rocks.

I have explained you that what do you mean by the raveling. Then you excavate some small blocks from the roof, they may fall in the cavity. When we were discussing about the tunneling, there we discussed about this term.

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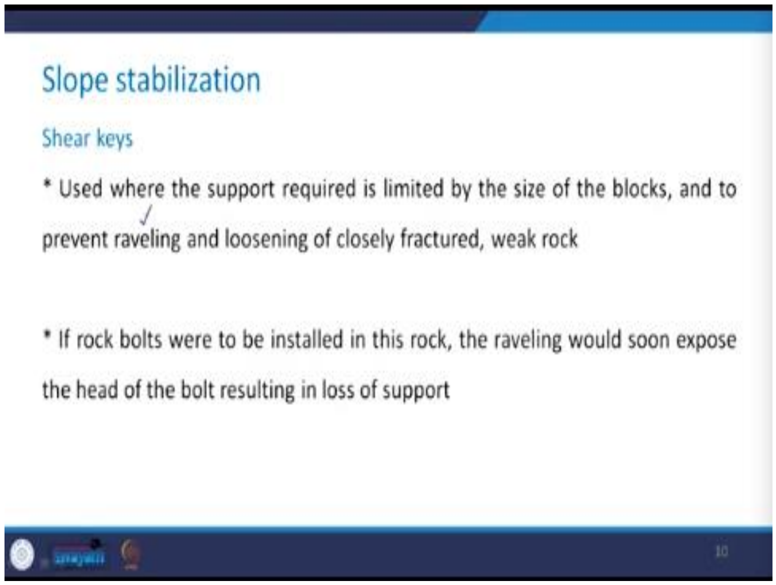

So, this provision of shear key is helpful in preventing the raveling. Now, if the rock bolts were to be installed in this type of rock, what would happen that the raveling would soon expose the head of the bolt that would result in the loss of the support. So, therefore, shear keys are more useful in such cases.

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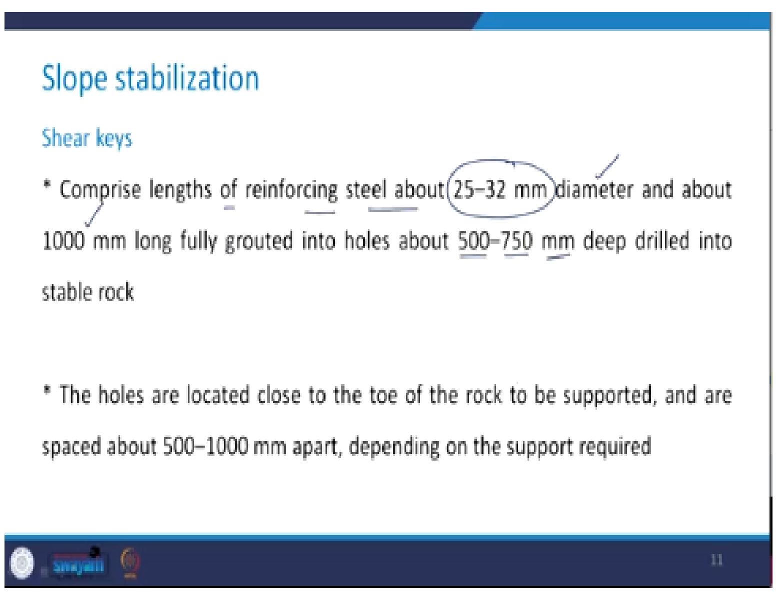

These comprises of the lengths of reinforcing steel about 25 to 32 millimeter diameter and about 1 meter long, fully grouted into the holes of about 500 to 700 millimeter deep drilled into the stable rock. These holes are located close to the toe of the rock which is to be supported and are spaced about 500 to 1000 millimeter apart depending upon the required support system.

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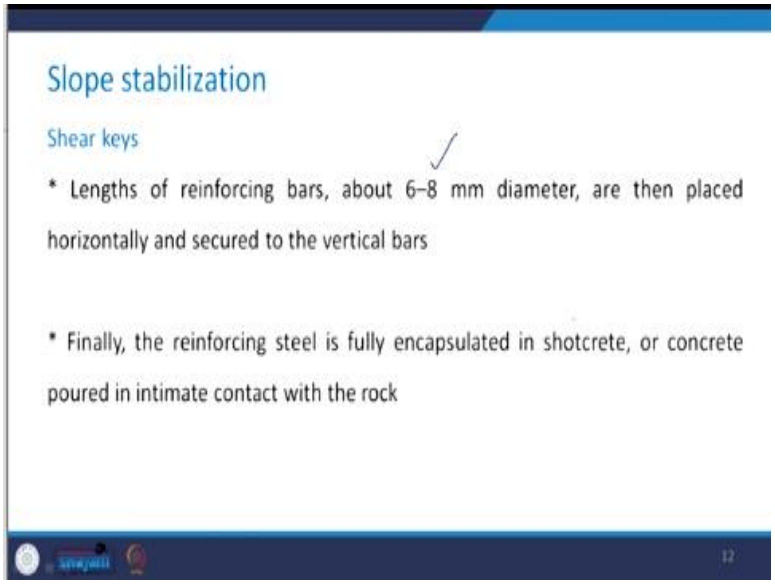

Then the length of the reinforcing bars, which can be of about 6 to 8 millimeter diameter are then placed horizontally and these are secured to the vertical bars. And finally, the reinforcing steel is fully encapsulated in shotcrete or concrete which is poured in intimate contact with the rock. So, this is what the shear key is.

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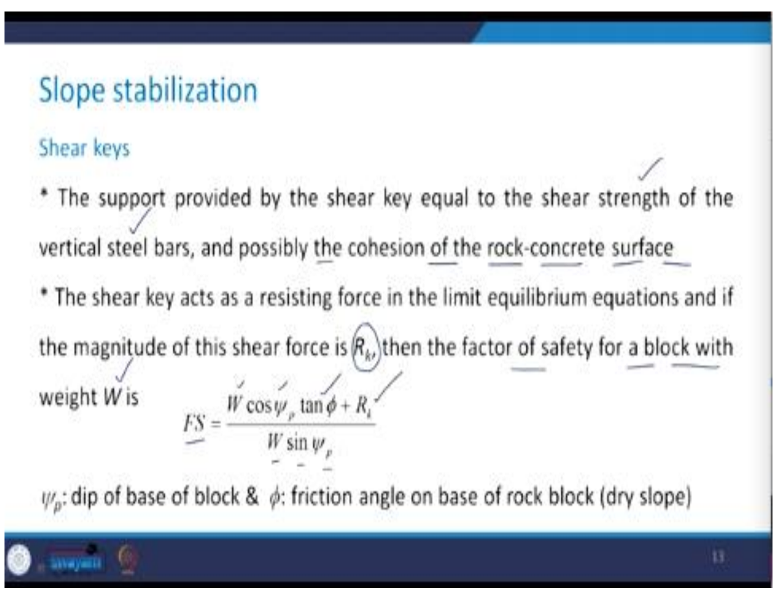

Now, what happens when you provide the shear key. The support which is provided by the shear key is equal to the shear strength of the vertical steel bars and possibly the cohesion of the rock concrete surface. These shear keys, they act as a resisting force in the limit equilibrium equations. Now say, if the magnitude of this shear force is represented by this term R_k, then this factor of safety of a block within the weight W is given as this term which is a factor of safety as

$$FS = \frac{W\cos\psi_p \tan\phi + R_k}{W\sin\psi_p}$$

Now, see if this shear key is not there, this term R_k will not be there in this expression. And in the presence of the shear key dip and the presence of R_k in the numerator of this expression, it enhances the value of this factor of safety and this results into the better stability of the rock slope, where this chi p and phi, they are representing the dip of the base of block and friction angle on the base of the rock block in case you have the dry slope.

In case, if there is water which is present there, so, accordingly you can have the expression for this factor of safety and obviously, shear force because of the shear key is going to be present in the numerator resulting the larger value of the numerator and therefore, better value of the factor of safety. These are used for the stabilization of dam foundations and abutments on a much larger scale. Now, when we will discuss about the problems related to dam foundations, there, you will see that how these shear keys are useful for the stabilization of the dam foundations and abutments.

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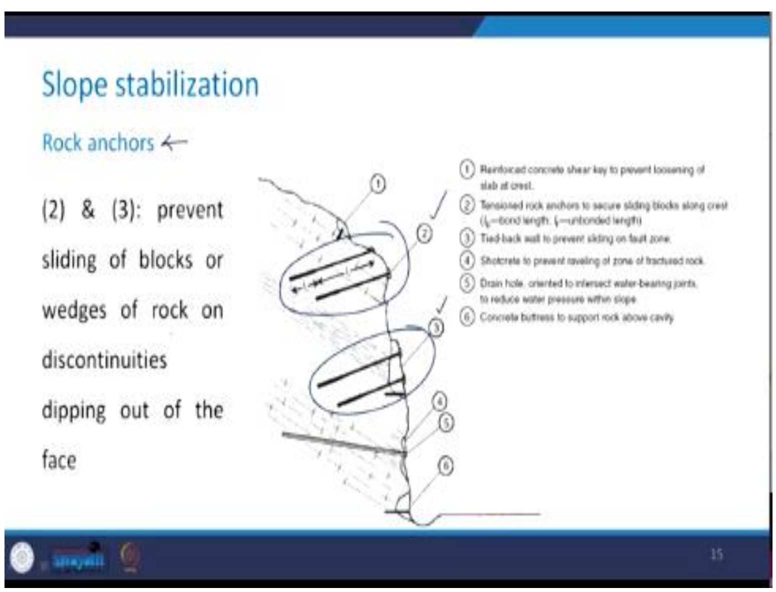

Coming to the next type of the slope stabilization measure which is rock anchors. So, here the second and the third measure, you can see here in this figure, this one and this one, these are the rock anchors. So, these prevent sliding of blocks or wedges of rock on the discontinuities, which are dipping out of the slope face.

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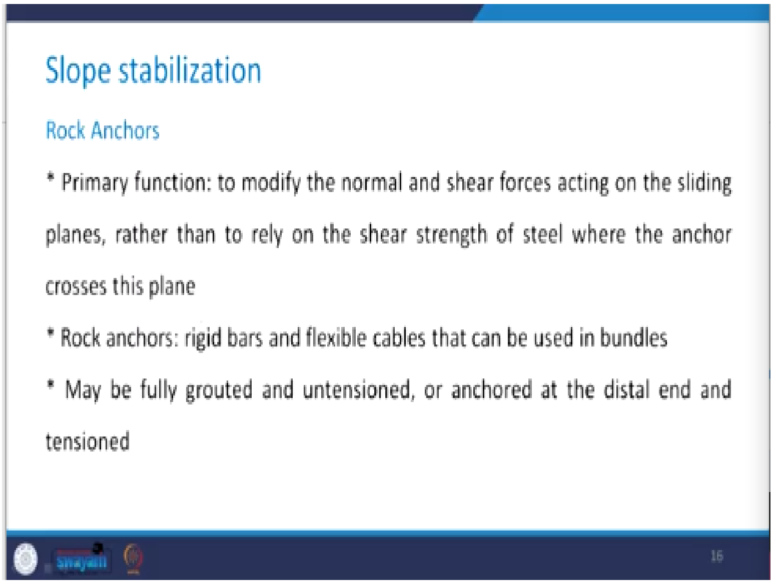

The primary function of rock anchors is to modify the normal and shear forces, which are acting on the sliding planes rather than to rely on the shear strength of steel, where the anchor crosses this plane. These rock anchors are rigid bars or they can be flexible cables, which can be used in bundles. They may be fully grouted and un-tensioned or they can be anchored at a distal end and they can be tensioned. So, basically, there can be 2 types of rock anchors. One can be pre-tensioned and the second one would be un-tensioned.

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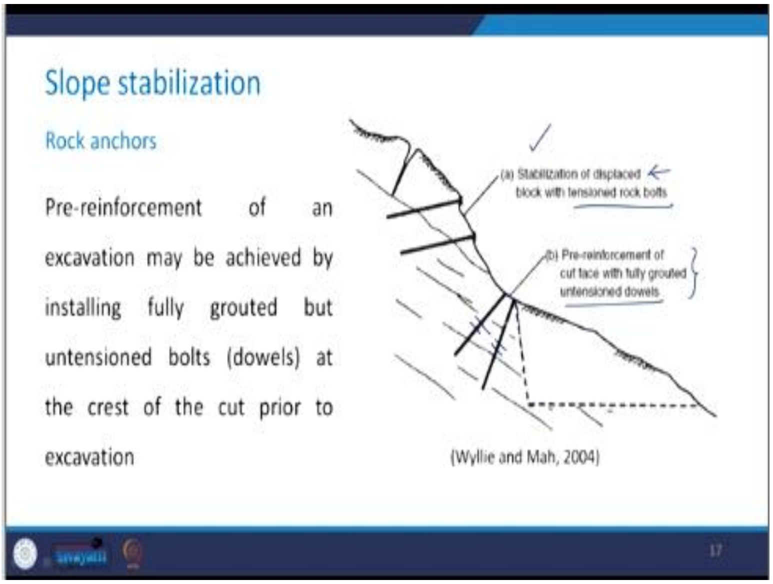

Let us see that how these 2 are different from each other. So, this figure shows you 2 sets of anchors. The first one is the stabilization of displaced block with the tensioned rock bolts. And the second one is pre-reinforcement of the cut face which is going to be this cutting face with fully grouted and un-tensioned dowels, which are given as these 2. Now, the pre-reinforcement of an excavation may be achieved by installing fully grouted but un-tensioned bolts or dowels at the crest of the cut prior to the excavation.

Take a look at this figure. These dotted lines, they show that the proposed excavation is going to take place in this particular manner. Now, before the excavation is carried out, you install these un-tensioned dowels in this particular manner and then you carry out this excavation. What will happen? Because of this stitching with the help of this pre-reinforcement will make this slope stable even after the excavation of this portion. So that is first category.

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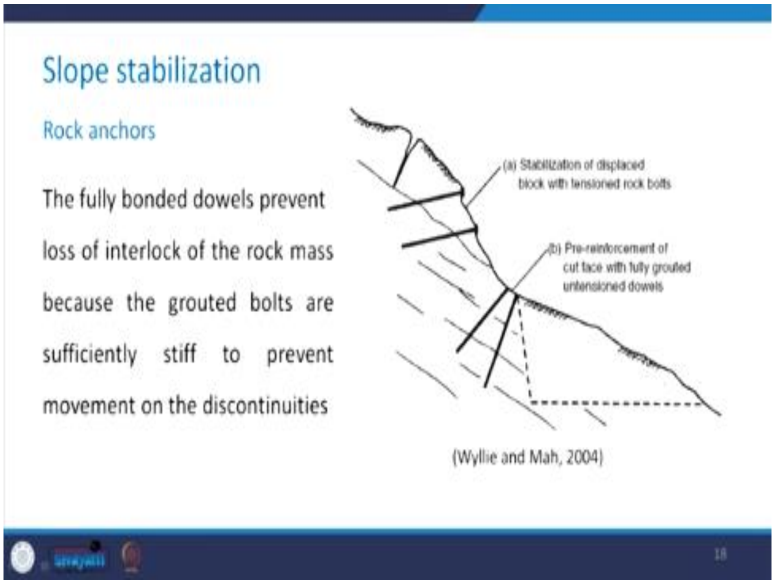

Now, what happens in case of this category is that the fully bonded dowels. They prevent the loss of interlock of the rock mass because the grouted bolts are sufficiently stiff to prevent any movement on the discontinuity. Here, the bonds are really great.

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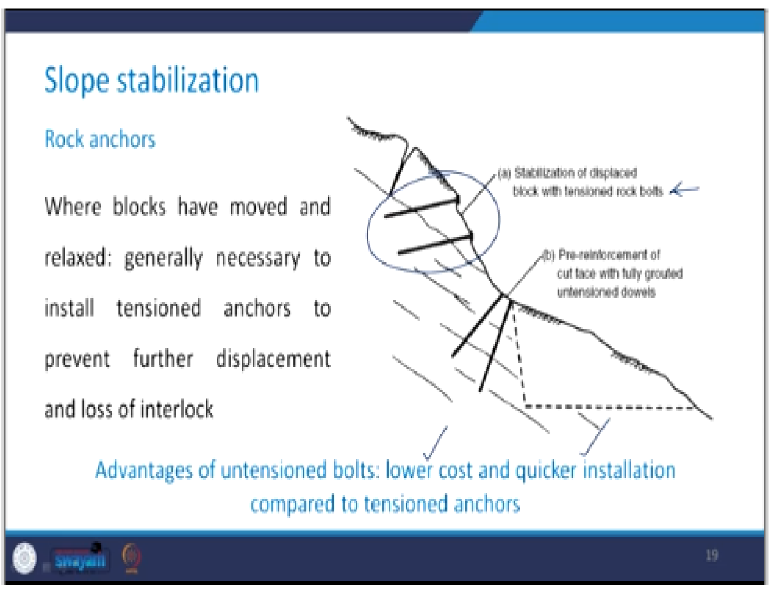

When blocks have moved and relaxed, then it becomes generally necessary to install the tensioned anchors to prevent further displacement and the loss of interlock, which has been shown here in this particular portion where these tensioned rock bolts have been used. The advantage of un-tensioned bolts include; they are lower cost and quicker installation as compared to the tensioned anchors. But both of these have their own merits and demerits.

So, according to the situation in the field, you need to decide that which one will serve the purpose in a better manner in a particular situation. Accordingly, you have to adopt it.

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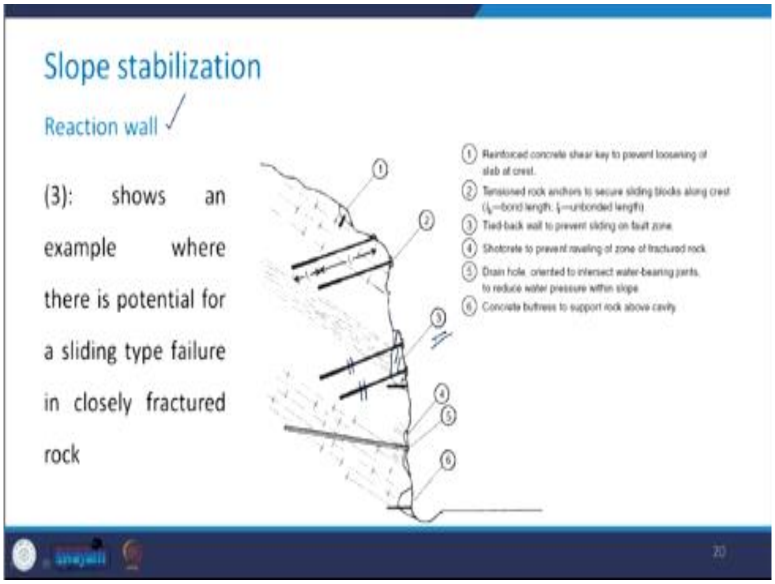

Now, the third type of slope stabilization measure involves the use of reaction wall. Here, you can see that although the rock anchors have been provided, but, at the same time here in this particular portion, this reaction wall has already been given. So, this third one is the example, where there is a potential for sliding type of failure in closely fractured rock.

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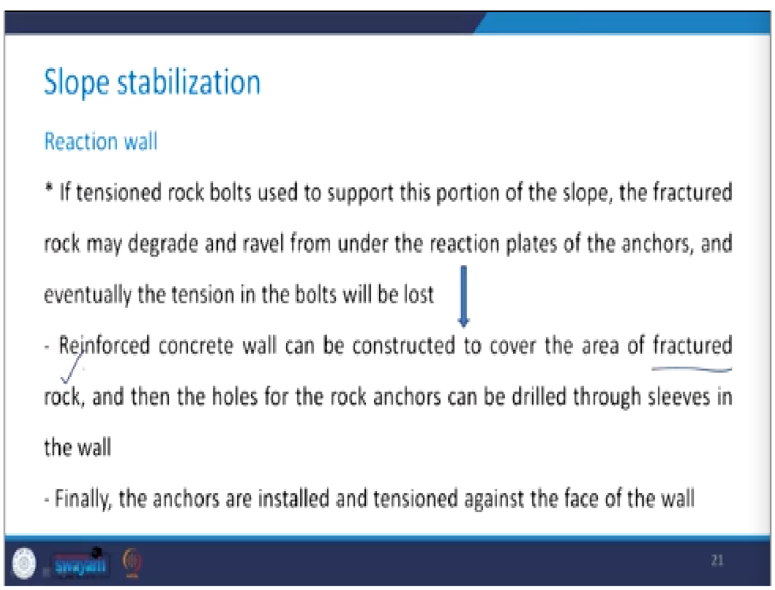

Now, if this tensioned rock bolts used to support this portion of the slope, what happens to the fractured rock? They may degrade and may ravel from under the reaction plates of the anchors and eventually, that tension which was there in the bolt, it will be lost, which is not desirable. Therefore, the reinforced concrete wall can be constructed to cover the area of this fractured rock and then the holes for the rock anchors can be drilled through the sleeves in the wall.

And then you can finally install the anchors and tensioned them against the face of the wall. So, that is how the anchors as well as these reaction walls both need to be provided in such type of situation.

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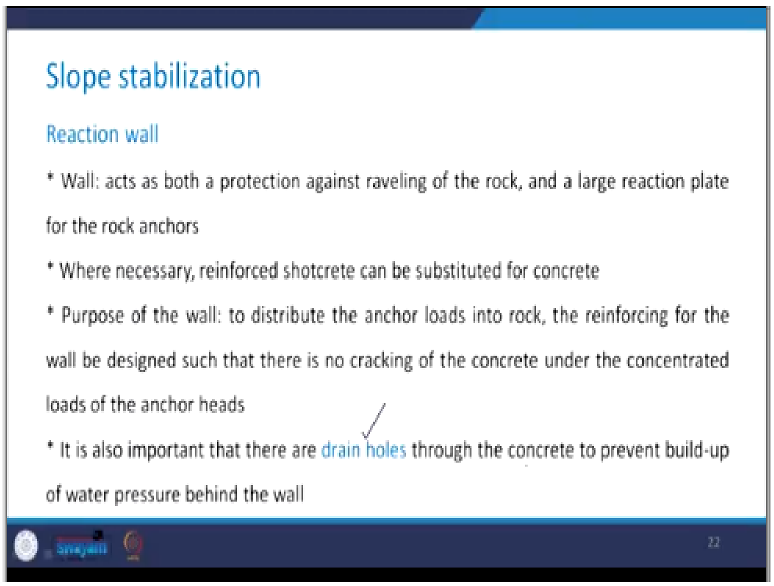

What happens to this wall? It acts as both the protection against raveling of the rock as well as a larger reaction plate for the rock anchors. Whenever necessary, reinforced concrete can be substituted for this concrete. The purpose of the wall is to distribute the anchor loads into the rock. The reinforcing for the wall should be designed such that there is no cracking in the concrete under the concentrated loads of the anchor heads.

Otherwise, what will happen that wherever these anchor heads are there, the load is concentrated and if the proper reinforcement has not been provided in the reaction wall, there is going to be cracking in the concrete and the purpose of providing this reaction wall shall be defeated. It is also important to provide the drain holes through the concrete in order to prevent the buildup of water pressure behind the wall.

It is exactly like the weep holes that you provide in case of the retaining walls. The fourth and very important very commonly adopted slope stabilization measure is the placement of shotcrete.

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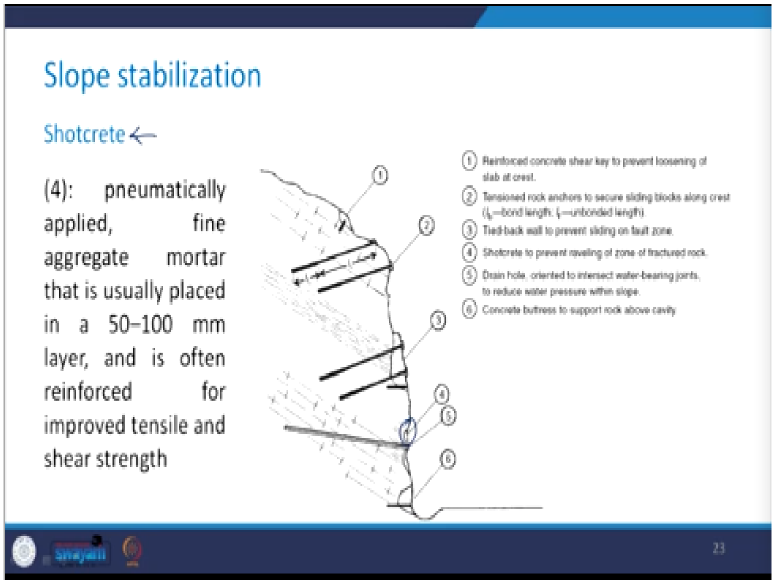

So, this is the fourth portion that is this one. This is very simple. It is pneumatically applied, fine aggregate mortar that is usually placed in a 50 to 100 millimeter thick layer and is often reinforced to improve tensile and shear strength. So, it is also used in case of the tunnels, in case of the slopes plus it is also used in combination with the rock bolting in case of the foundations which are there on the weak rocks. We will be discussing these in detail later.

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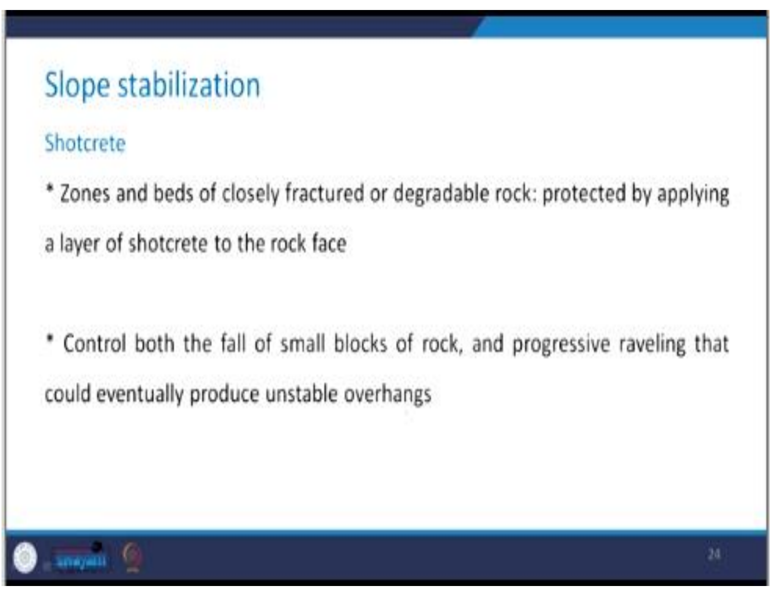

The zones and the beds of closely fractured or degradable rock, they are protected by applying a layer of shotcrete to the rock face, provision of the shotcrete control both the wall of small blocks of rock and progressive raveling which could eventually produce unstable over hacks. So, this shotcrete therefore, becomes very, very important. It provides very little support against sliding for the overall slope and the primary function of the shotcrete is the surface protection.

Another component of the shotcrete installation is the provision of the drain holes to prevent buildup of the water pressure behind the face that has been shown here you can see that this 5 number which is the drain hole oriented to intersect water bearing joints to reduce the water pressure within the slope.

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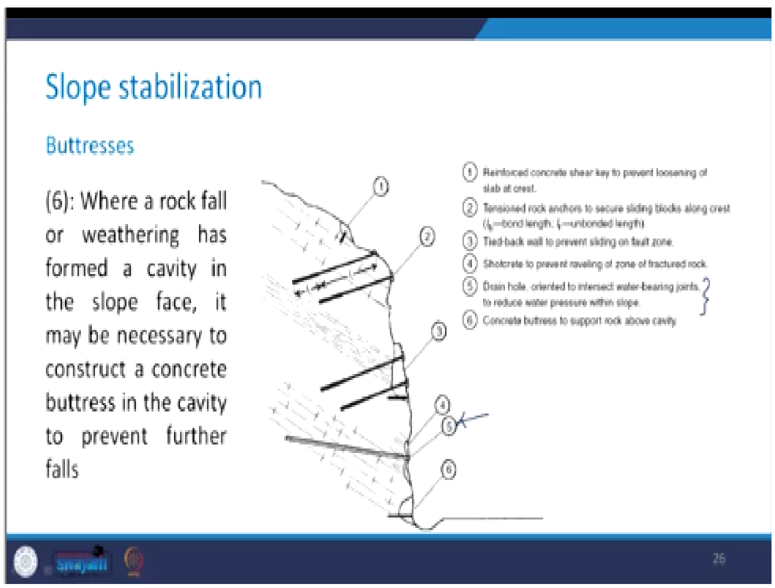

So, water can pass through this drain hole and can come out. So, that the water pressure is not built inside the slope. Now, the sixth one is the provision of the buttresses as has been shown here in this particular portion. These are the concrete buttress to support the rock which is above the cavity. So, in this case where a rock fall or the weathering has formed a cavity in the slope face.

It may be necessary to construct concrete buttress in the cavity to prevent further falls. How? See these buttresses, they fulfill 2 functions.

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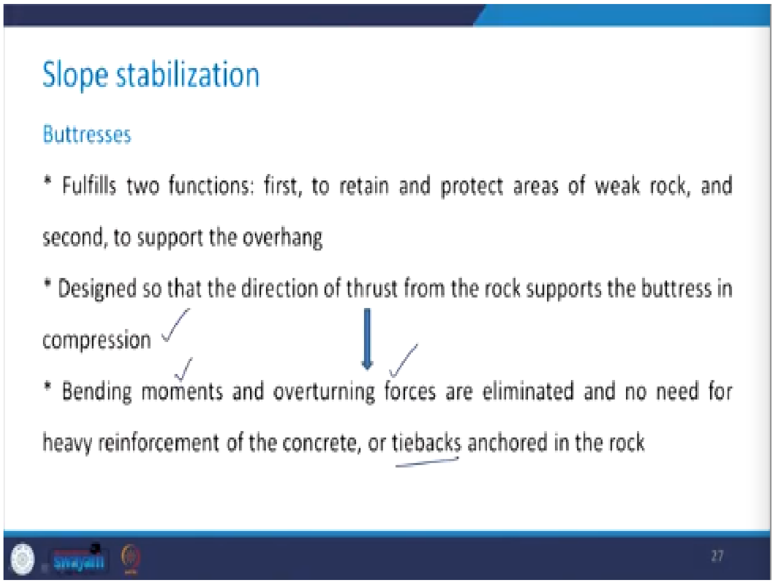

First is to retain and protect the areas of weak rock and second is to support the overhang, because when the cavity is created, the portion which is there on top of that it will be kind of an overhang. And when you provide the buttress, it supports that overhang. These are designed so, that the direction of the thrust from the rock, it supports the buttress in compression. What happens? Because of that, that bending moments and overturning forces are eliminated and there is no need for heavy reinforcement of the concrete and tiebacks anchored in the rock.

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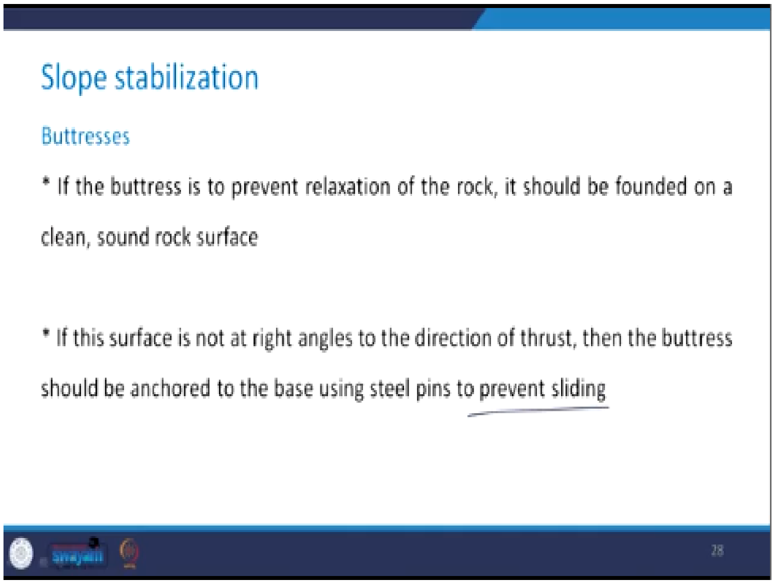

Now, if the buttress is to prevent relaxation of rock, it should be founded on a clean sound rock surface. If this surface is not at the right angle to the direction of the thrust, then this buttress should be anchored to the base using steel pins in order to prevent the sliding. So, these conditions should be kept in mind. When one designs such type of slope stabilization measures which include the provision of buttresses.

Also, at the top of the buttresses, it should be poured that it is in contact with the underside of the overhang.

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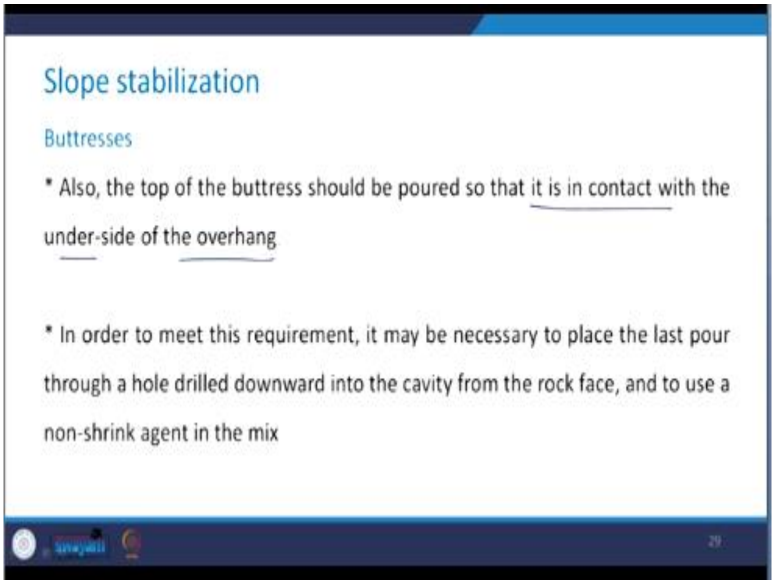

In order to meet this requirement, it may be necessary to place the last pour through a hole which is drilled downward into the cavity from the rock face. And to use a non-shrink agent in the mix so, that it remains as it is and buttress is in contact with the underside of the overhang because if this contact is not established. The purpose of the provision of buttress will not be served. Now, this was all about the stabilization of the rock slope using the reinforcement techniques.

I mentioned to you that the slopes can also be stabilized by the removal of the rock. So, this figure gets you the idea about various steps, which are adopted when we take up the stabilization of the rock slope by rock removal.

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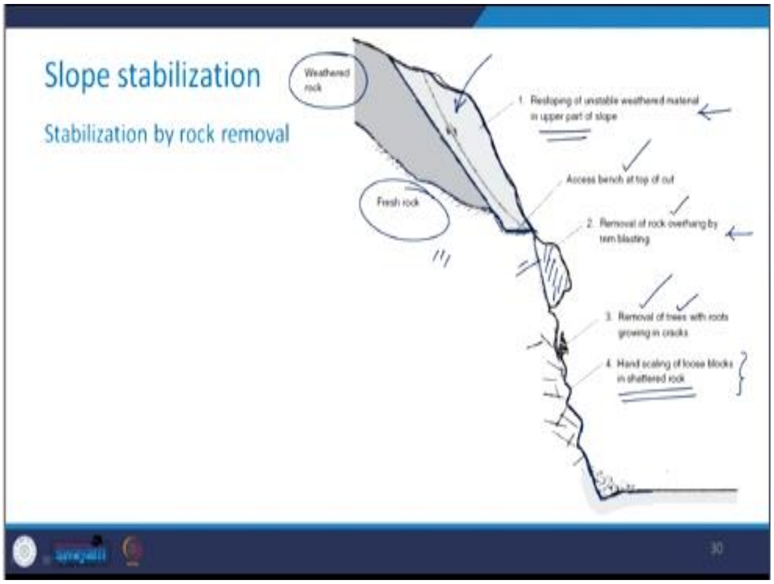

So, here you can see that this part or this boundary forms the boundary between the fresh rock which is here and the weathered rock which is here. So, the first step is going to be that we are going to re-slope this unstable weathered material in the upper part of the slope. So, which was earlier like this, now, this can be re-sloped in this particular fashion. So, that means we are removing this portion.

Then there would be the excess bench at the top of the cut. And the second step will include the removal of rock overhang by the trim blasting. So, you see that this is not divided material, but the rock only. So, using the trim blasting, this overhang would be removed. Then if there are presence of the trees, which have roots growing in cracks, then such trees should be removed, because ultimately what they would tend to do is they would try to widen those cracks.

So, these should be removed, then hand scaling of loose blocks in the shattered rock is carried out in order to have the profiling or the re-profiling of the slope. So, this is how using the rock removal, we can stabilize the slope. So, I discussed with you various methods for the stabilization of rock slopes. Depending upon the condition, depending upon the requirement in the field, you can choose appropriate measure and go for appropriate design before installing them or before applying them in the field for the stabilization of rock slopes.

So, this finishes our discussion on this chapter which was related to rock slope stability. In the next class, we will start our discussion on a new chapter which is foundations on weak rocks. We will learn about different aspects pertaining to the foundations which are to be laid on rocks, how to determine their bearing capacity. And in case the rock is very poor or the rock mass is very poor, how we can provide some kind of a strengthening measure.

So, that the rock has sufficient bearing capacity in order to handle the load that is coming from the superstructure to the foundation and then go to the rock mass. So, all these aspects, we will discuss in the next class. Thank you very much.