Rock Engineering
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Lecture-19
Concept of Rock Mass,
Factors Affecting Discontinuities

Hello everyone. In the last class we started our discussion on engineering classification of rocks and rock masses. And I gave you the idea about Deere and Miller classification which is applicable to intact rocks. I also introduced you the concept of rock mass with the help of RQD which is Rock Quality Designation. Today we will extend our discussion and we will have some more discussion on the rock masses.

And what all are the factors which affect the behavior of the discontinuities? That also we will see in detail. So, first let us see that when we have intact rock and rock mass, how to differentiate? By this time, you know that intact rock is free from any kind of discontinuity. However, there can be the presence of micro fractures, which we do not count under the category of discontinuities. As for as rock mass is concerned, as a whole, when intact rock plus discontinuities both are there in the field, which is most of the time, that we call as rock mass.

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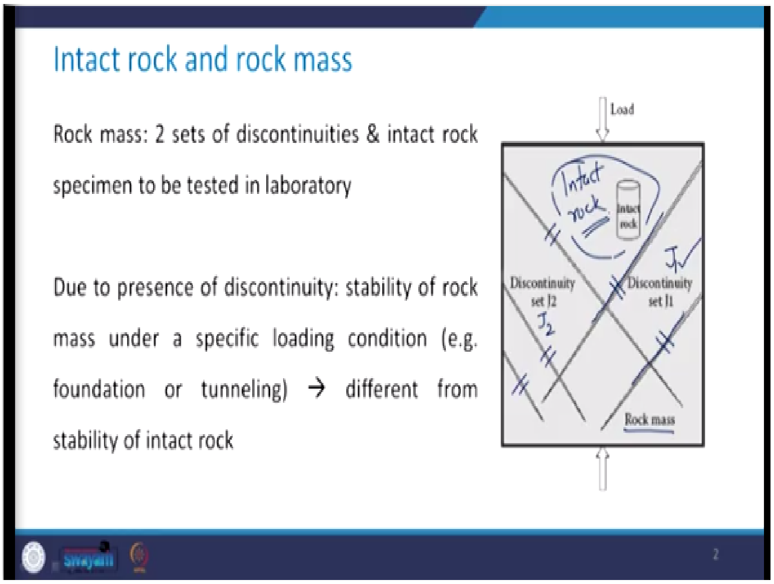

So, here in this picture, you can see that a rock mass has been shown, which has 2 sets of discontinuity. So, let us say the first set is J_1 here and the second set is J_2, that means you know that how we define the discontinuities set. So, in a discontinuity set the discontinuities are more or less parallel with same spacing. So, you see, in this case, this discontinuity is kind of parallel to this, so that is why we are calling this as discontinuity set 1.

Similarly, this one, this and this, they are continuity set 2. And I mentioned to you in the previous class, as we keep on reducing the sample size, the most heterogeneous rock can behave in the isotropic and homogeneous rock and intact rock. So, if I take out the specimen from this portion, so whatever will be that specimen that will be of intact rock. So, due to the presence of discontinuity, what happens to the stability of the rock mass under a specific type of loading?

That loading can be because of the construction of the foundation or tunneling or any other type of a structure that is going to come up. That is going to be different than the stability of the intact rock. So, it is only the presence of discontinuity which makes the strength characteristic of rock mass different than that of the intact rock.

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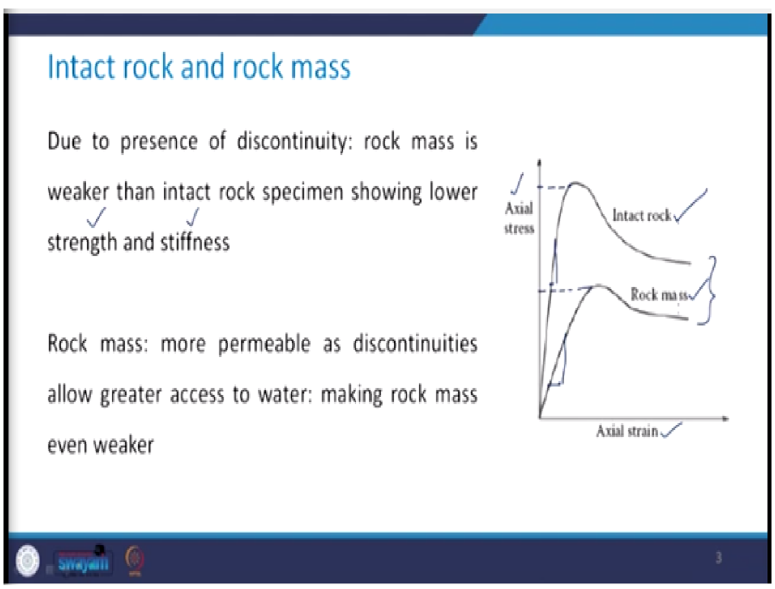

Due to the presence of the discontinuity, we have seen that rock mass is weaker as compared to the intact rock specimen. And when it is weaker, obviously, it will show lower strength and stiffness. So, here in this figure, axial stress versus axial strain plot has been shown. So, the upper one is for the intact rock and lower one is for the rock mass. And you can see that if you compare these two, see the peak strength for the intact rock is somewhere here and for the rock mass it is somewhere here.

Similarly, it is stiffness, it is like this in case of the intact rock and in case of the rock mass it is like this. So, see, it is not only the strength but stiffness, also reduces when you compare intact rock with the rock mass. Because of the presence of the discontinuities, rock masses are more permeable and therefore they allow greater access to the water. And you know that in the presence of the water, rocks get weaker.

So, that is another reason that rock mass is weaker as compared to the intact rock. What this water does? It reduces the friction along the discontinuities and increases the pore water pressure thereby reducing the effective stresses.

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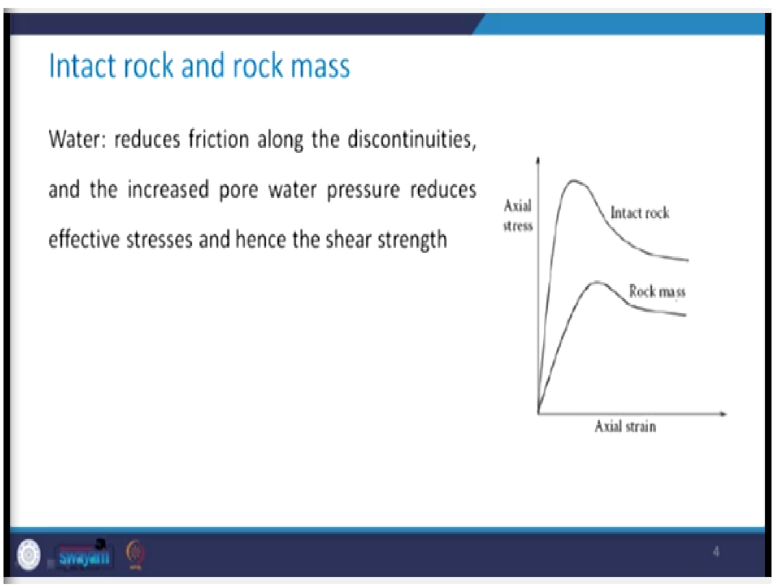

And once the effective stresses are reduced, shear strength will be lower. So, because of the discontinuity strength and stiffness are going to be less for the rock mass as compared to intact rock. Because of the discontinuity, rock mass is more permeable, which further reduces the effective stress and therefore the shear strength.

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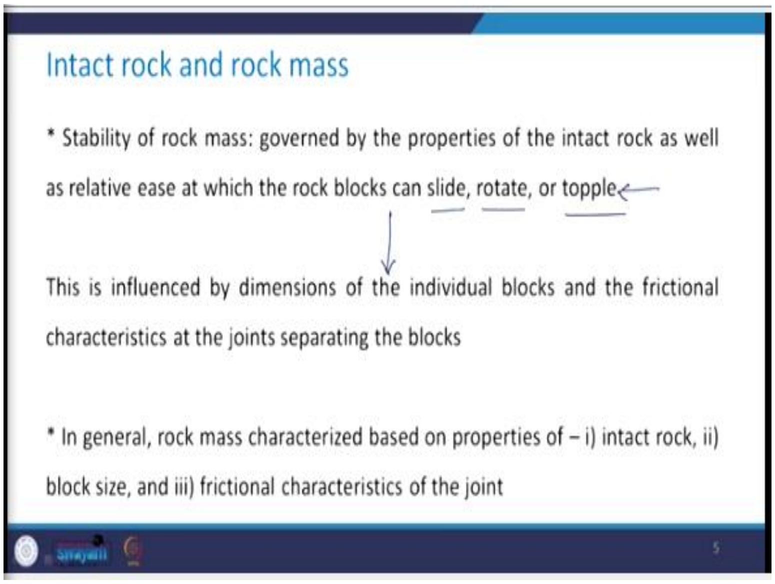

In view of all these facts, the stability of rock mass is governed by the properties of the intact rock plus the ease with which the rock blocks can slide, rotate or topple. Why these things will happen? Because of the presence of discontinuity. And this whole thing that is sliding, rotating or toppling is influenced by the dimension of the individual blocks and frictional characteristic at the joints which are separating these blocks.

So, if these joints are not there, there are not going to be any blocks and therefore there would not be any question of all these phenomena to happen. So, in general the rock mass is characterized based on the properties of intact rock, block size and frictional characteristic of the joint.

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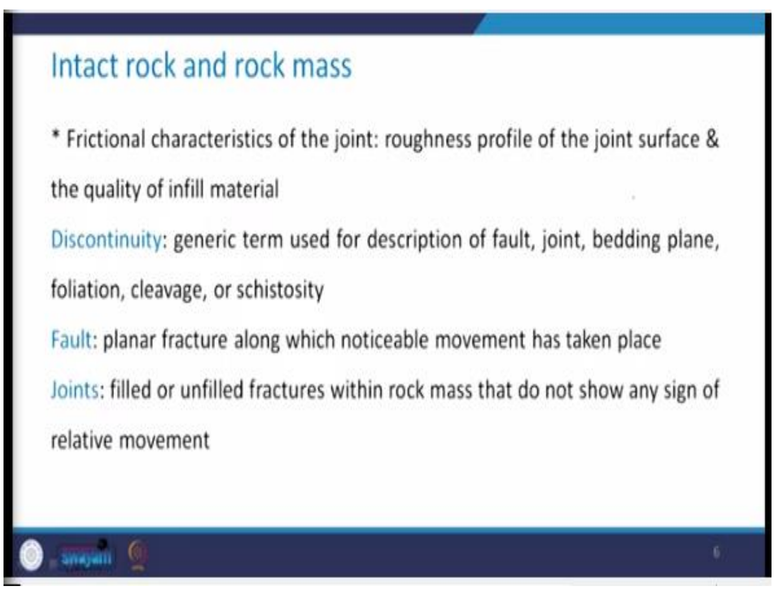

Frictional characteristics of the joint, what is it? Because we have already discussed about the intact rock but this aspect, that is, frictional characteristic of the joint we have not discussed yet in detail. So, basically this is the roughness profile of the joint surface and the quality of the infill material. From where this infill material is coming? In the field wherever there are joints, either they will be tight or they will be open joints.

If they are tight or close joints, it is fine. The wall of the rock, they will be in touch with each other, in contact with each other. But if the joint is open, then it may happen that some material, like for example clay has been deposited in between that open space between the two-rock wall. So, that material is called as infill material. Discontinuity is a general term which is used for the description of fault, joint, bedding planes, foliation, cleavage plane or schistosity.

These things we have already discussed, and I already have told you about various elements of these geological structures and the discontinuities. Now once again, just for the completeness, faults are the planar fracture along which noticeable movement has already taken place. Joints they can be filled or unfilled fractures within the rock mass and there will not be any sign of the relative movement on either side of the joints in the rock block.

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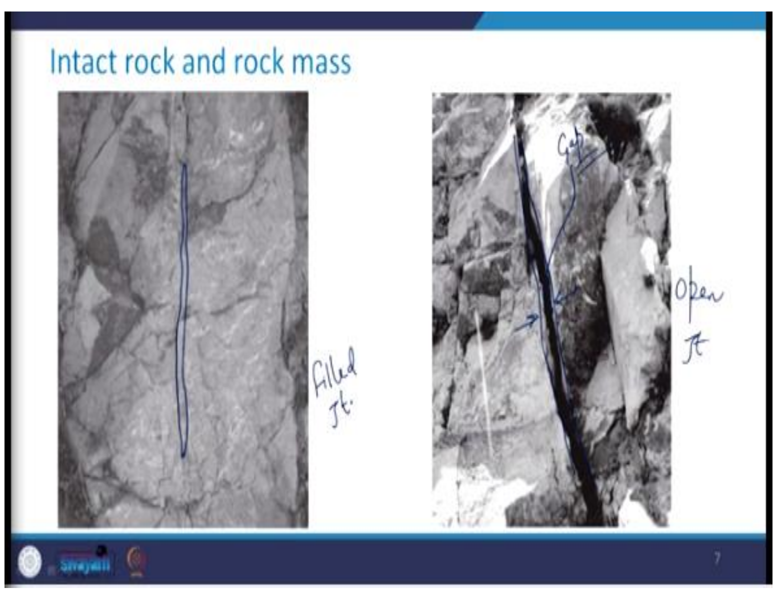

Take a look here. There are 2 pictures, one is showing a filled joint and this is an open joint. Just focus here, see this is the joint surface in which some infilling material has been deposited thereby filled the joint. However, in this case you can see that this surface and this surface of the joint wall, they are not in contact with each other. There is a gap between these. So here this is what is the gap. So we are saying that it is going to be open joint.

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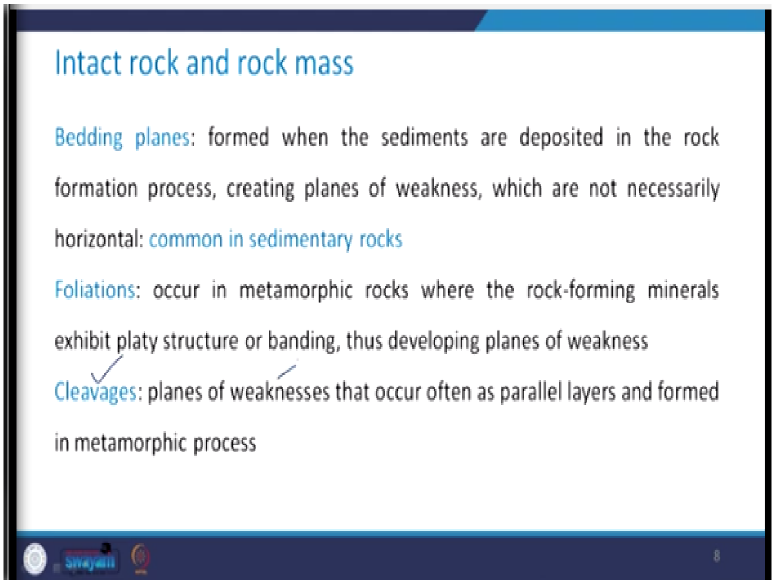

So, either of the condition may exist in the field. Then coming to the bedding planes, these are formed when sediments are deposited during the rock formation process. They creating planes of weakness which may not necessarily be horizontal and this is pretty common feature in sedimentary rocks. Then we discussed about the foliations also which was occurring mainly in metamorphic rock, where the rock forming minerals, they exhibit platy structure or banding and therefore developing the planes of weakness.

As far as cleavage planes are concerned, these are the planes of weakness, that occur often as parallel layers and they are formed in the metamorphic process. All these things we have discussed in detail with the help of pictures and relevant figures. Then, the next category is schistosity.

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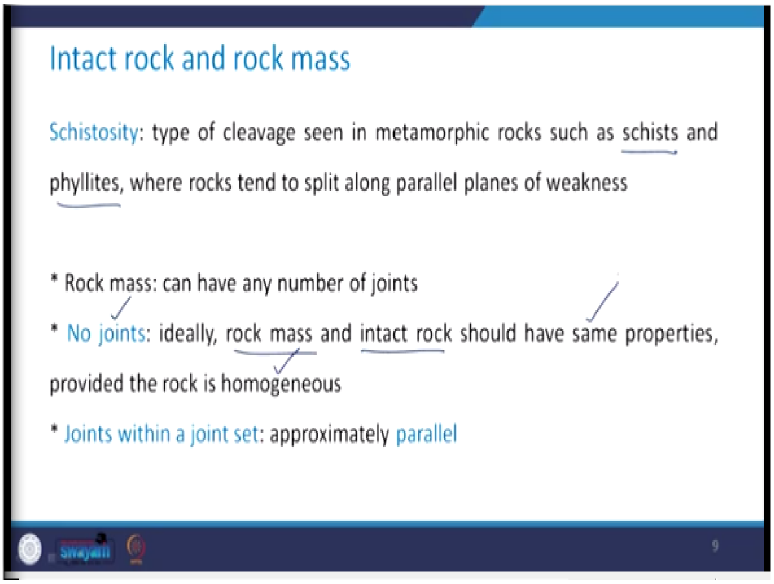

It is the type of the cleavage which is seen in metamorphic rocks like schists and phyllites, where the rocks tend to split along the parallel planes of weakness. Now this rock mass can have any number of joints. If there are no joint, then ideally the properties of the rock mass and intact rock they should be same, provided the rock is homogeneous. If the rock is heterogeneous and there is no joint, then we cannot say that the property of the rock mass and intact rock they are going to be same.

But if the rock is homogeneous and there are no joints, then rock mass and intact rock, they have same properties. Now joints within a joint set they are approximately parallel. We have had the discussion on this as well. How to determine the spacing for a joint set? So, the distance between the adjacent joints in the same set is defined as the spacing.

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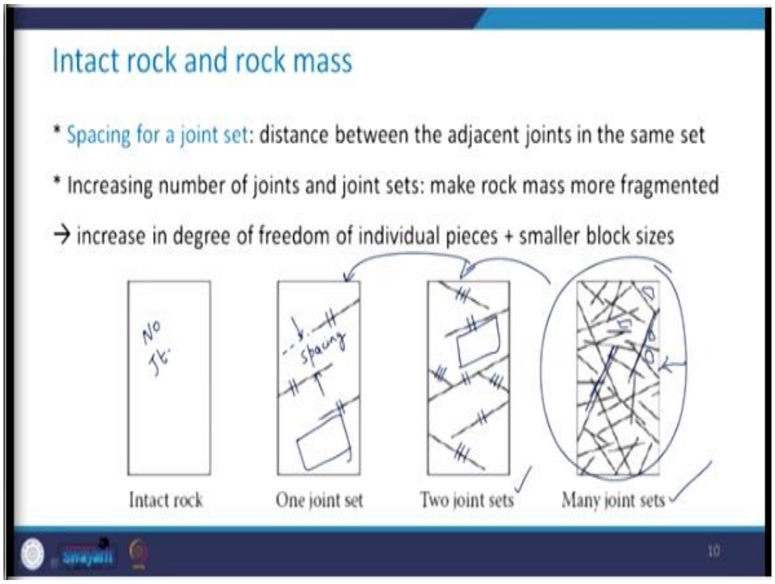

So, here you can see four figures are there, the first one is intact rock where there is no joint. The second one has only one joint set, how do we decide that it is one joint set? You see all these joints they are approximately parallel to each other. Now how I am going to determine the spacing for a joint set? You see if I just extend it, so perpendicular to this that is the shortest distance between the 2 adjacent joints, this is what is going to be the spacing.

Come to the next figure, here you have 2 joint sets. So, you see this, this and this they are parallel. Then these, these are parallel to each other. So, there are 2 joint sets. Then the last one has many joint sets, because here we really cannot make out how many joint sets are there, because you see that this line, this line is parallel to this line. And likewise, there are many combinations of such parallel lines, so we are calling this as many joint sets.

So, when the number of joints and joint sets, they increase they make the rock mass, more fragmented. And this further increases the degree of freedom of individual pieces plus the smaller block sizes. So, you see that in this case the block sizes are smaller as compared to all these cases. In this case the block size you can obtain of this, in this one it is a little bit bigger however in this case you see, it is a small block size which you will be able to get from here.

So, when you have a greater number of joints and join sets, rock mass is more fragmented. And this results into the increase in the degree of freedom of individual pieces plus there is going to be smaller block sizes, when you have more number of joints and join sets. Now coming to the factors which affect the discontinuities, some of the factors have been listed here.

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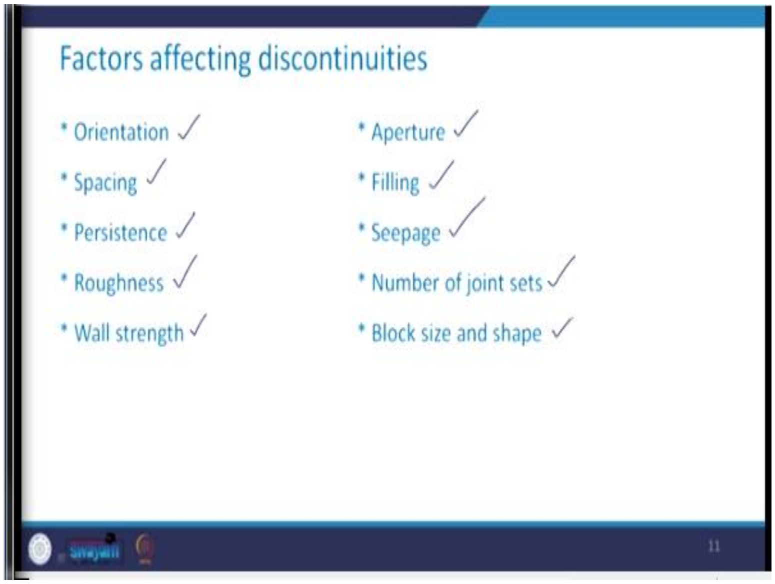

These are all with reference to discontinuities, orientation, spacing, persistence, roughness, wall strength, aperture, filling, seepage, number of joint sets, block size and shape. So, we will discuss these one by one in detail because until and unless the importance of each of these is clear to you, you will not be able to appreciate the need for declassification of rock mass plus there are going to be various terms which we will be using pretty often while learning about the classification of rock mass.

And therefore, it is extremely important for you to know that what those terms mean. Like if I say that the joint has this much of the aperture, you should know how we are defining the aperture? How we can determine the aperture in the field? So, with this goal in mind, let us take a look on these factors one by one which influence discontinuities significantly. So, to start with the first one is orientation, we have discussed about this when we were discussing the geological structures and their graphical representation.

So, you know that to represent any discontinuity as far as it is orientation is concerned, we would need dip and dip direction. So, the orientation of the discontinuity is measured as dip and dip direction.

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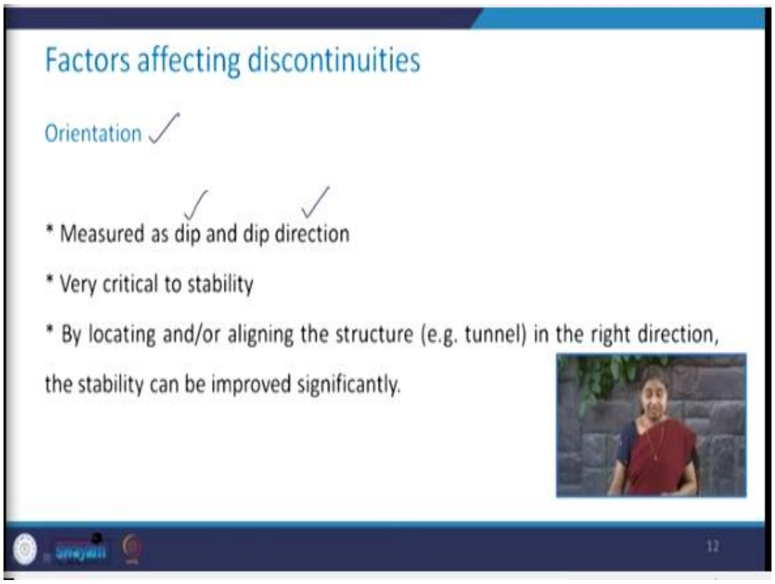

I have also shown you that how critical the orientation of these discontinuities is to the stability of any structure, whether that is tunneling, whether it is slope stability or whether it is foundations on rock mass. By locating or and by aligning the structure in the right direction, the stability can be improved significantly. Especially this is true in case of the tunnel, say you have the space and in one direction, first you decide that this should be the tunnel axis.

But then the orientation of that tunnel axis is in such a manner that it is really not favorable for the construction activity. Then you can change it a little bit and see whether the changed orientation of that axis is going to give you a better picture or not. So, therefore by locating or by aligning or both the things location as well as alignment of the tunnel in the right direction, and that can help you in improving the stability significantly. So, therefore this orientation is one of the most important factors which affects the discontinuity.

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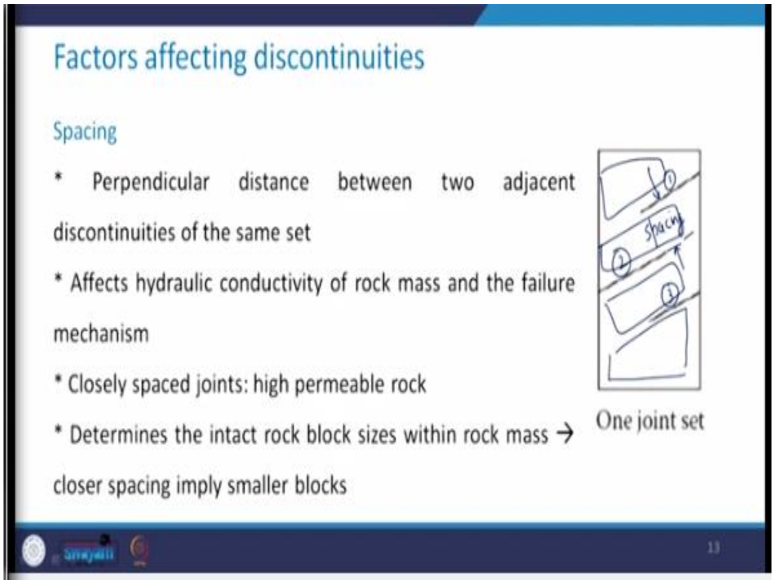

The next term is the spacing of the discontinuities. Perpendicular distance between 2 adjacent discontinuities of the same set. So, let us say that here it is one joint set, so here this is the perpendicular distance between the 2 adjacent joints, and I will call this as spacing. These affect the hydraulic conductivity of rock mass and also the failure mechanism. If you have very closely spaced joints in a rock mass, then that is highly permeable.

It determines the intact rock block sizes within the rock mass, that means, if you have closer spacing it will result into smaller blocks. Like here, you have 3 joints 1, 2 and 3, block sizes can be taken like from this portion. Like this. Block sizes can be taken.

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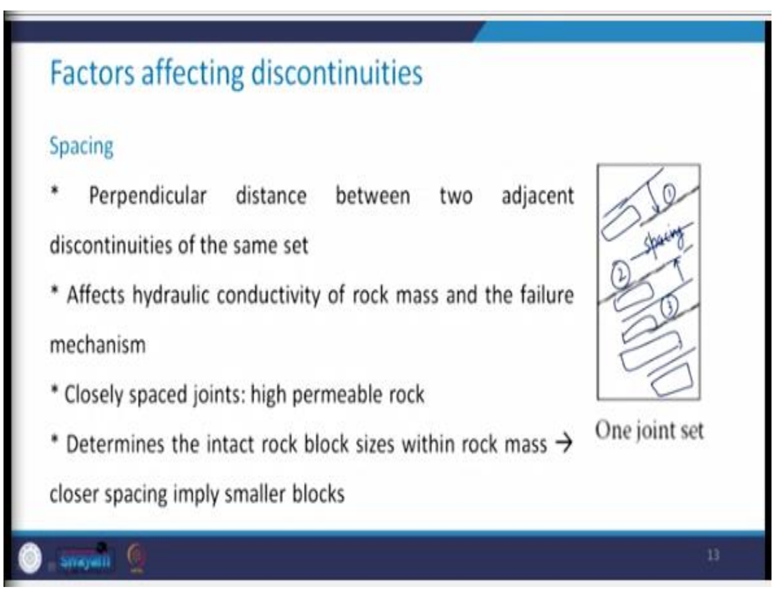

Now see I introduce a few more joints, then what will happen? Let us say I introduce here one more, here one more, here one more and like this, you have few more joints are there, now what will happen? The block size, you see, that now it is this. So, what I mean to say is when you have closer spacing of the discontinuities, it results into the smaller blocks. Based upon the spacing the classification of the discontinuities have been given.

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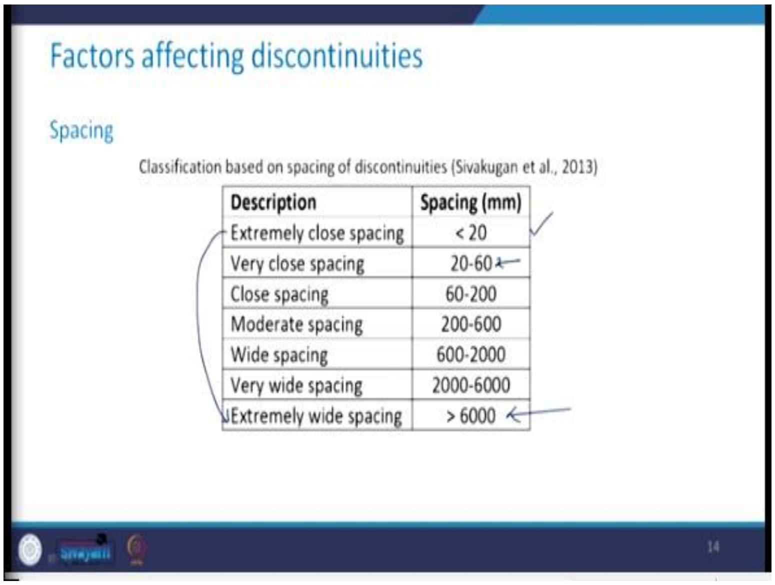

That is extremely close spacing means the spacing is less than 20 mm, very close spacing 20 to 60 mm. And as the spacing will keep on increasing the description changes from extremely close spacing to extremely wide spacing. You see in case of the extremely wide spacing the spacing is of the order of more than 6000 mm. So, if you have the spacing which you can measure using the tape there in the field, accordingly you can describe that discontinuity with respect to it is spacing.

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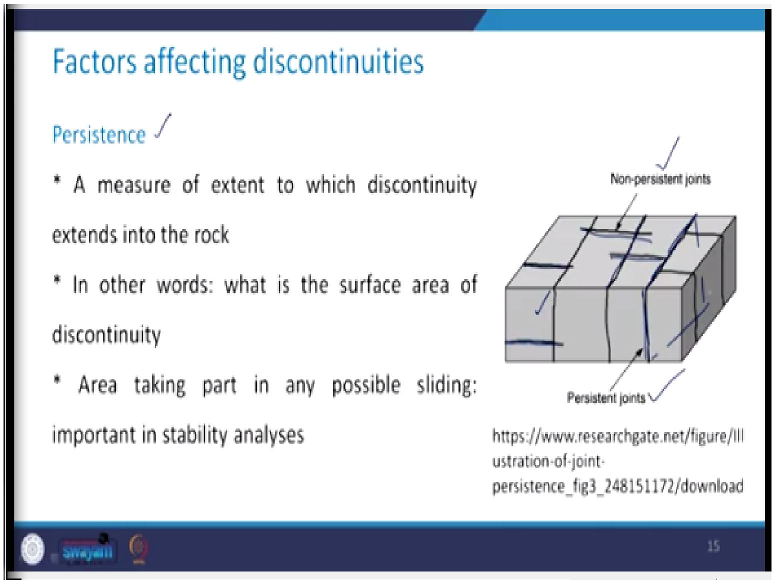

Next property or the factor which influence the discontinuities is persistence. Very important one and it is difficult to measure, so we have to take some idea in the field. First understand what exactly is the persistence? This is a measure of extent to which this discontinuity extends into the rock, take a look at this figure. Let us say this is the exposed surface, fine. So, you have the joints, one joint is like this and then rest of the joints are kind of vertical as shown in this figure.

Now is by some mean let us say that we get to know that this joint is extending into the rock mass like this. However, this joint set you see it is not extending, it is like this, so these are called as non persistent joints. However, which is extending in the rock that is called as persistent joint. So, in other words this signifies that what is the surface area of the discontinuity. So, you see that in this case the surface area of the discontinuity will be something like this.

So, the area taking part in any possible sliding that is very important in the stability analyses and obviously that area which is taking part in any possible sliding is related to this term persistence. So, one needs to be careful about this factor.

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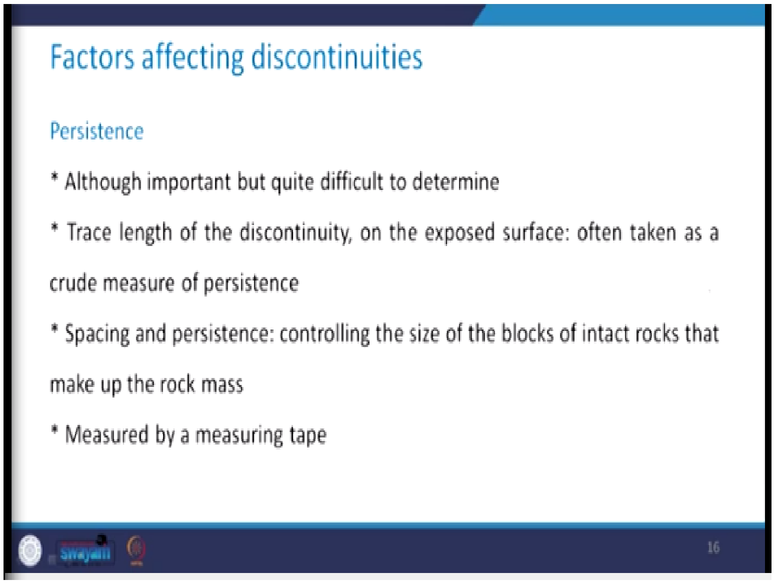

Although it is very important from the stability point of view, but it is very difficult to determine. So, as a crude measure of persistence, the trace length of the discontinuity on the exposed surface can be taken as the persistence. Please remember, trace length of the discontinuity which is exposed on the surface, that can be taken as a crude measure of persistence. Spacing and persistence, they control the size of the blocks of intact rock, that make up the rock mass.

How to measure this persistence in the field, is with the help of measuring tape. So, basically, whatever is visible that is whatever is the length trace length of the discontinuity which is visible on the exposed surface as a crude measure that can be taken as the persistence. Based upon the value of this persistence or the trace length one can describe the joints or the discontinuities with respect to persistence.

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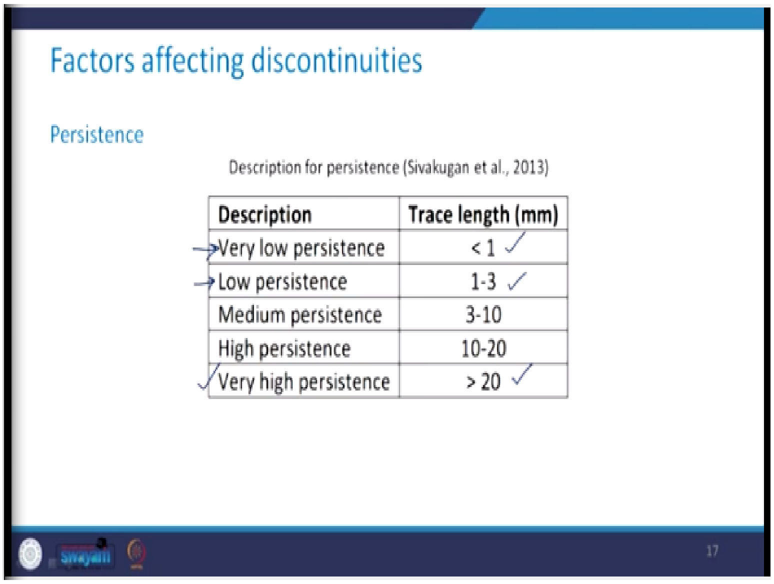

If the trace length is less than 1 mm, then it is very low persistence, if it is 1 to 3 mm, then it is low persistence and so on. If it is more than 20 mm, then it is very high persistence. So, this is how the description for the persistence can be defined based upon the trace length of the discontinuities.

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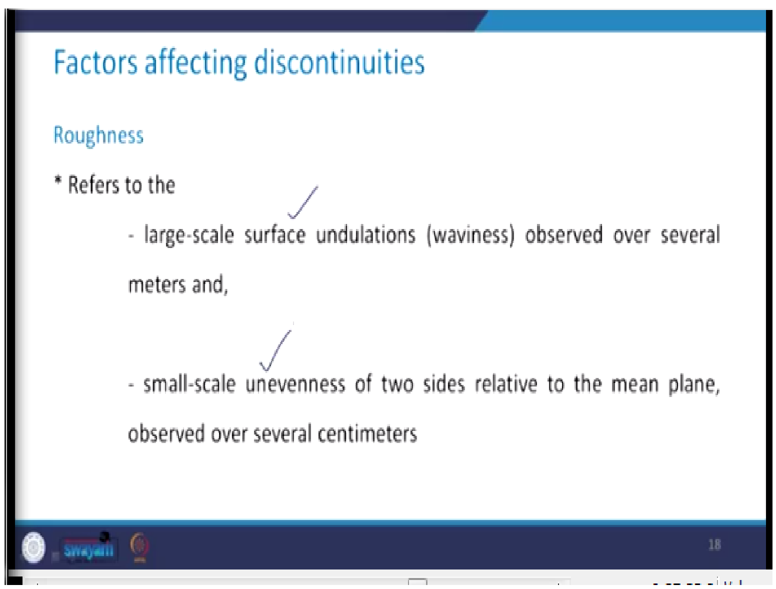

Coming to the next factor that is roughness. It is very, very important because most of the stability analysis when you carry out for the rock mass, it is this factor which contributes a lot towards the strength characteristic. When I say roughness, these refer to 2 things, one is the large-scale surface undulations or the waviness which is observed over several meters. And the second one is small scale unevenness of 2 sides related to the mean plane which is observed over several centimeters.

One is large scale, second one is small scale, the large scale runs over several meters however the small-scale unevenness observed over several centimeters.

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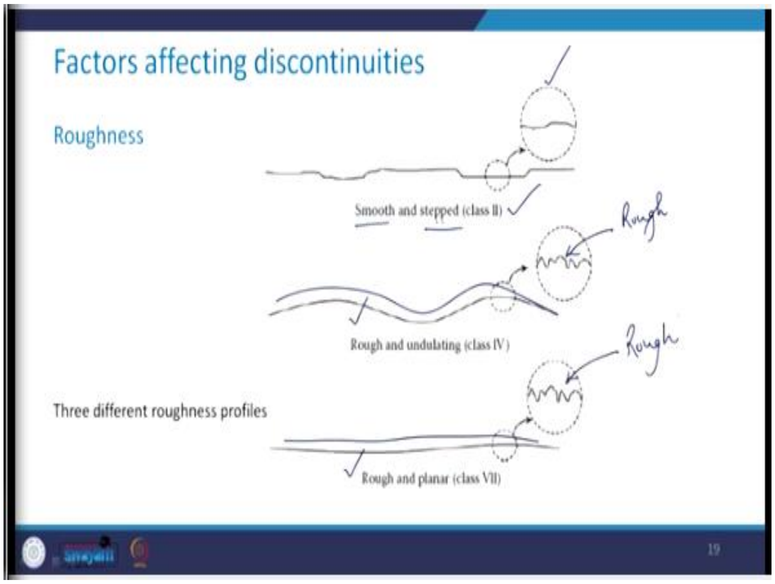

From this figure, take a look, there are 3 different roughness profiles which have been shown. So, the first one is class II, that is smooth and stepped, you can see here if I take a small portion and zoom it here like this, so you see what do we mean by smooth and stepped. Then the next one is rough and undulating. So, you see it is undulating and when you take the close up of it, so you see here it is rough.

Likewise rough and planar, so what is the difference between this and this? In this case, it was undulating while in this case it is more or less planar. And when you take the close up of a part of this. Again, you see here it is rough, let us further understand this.

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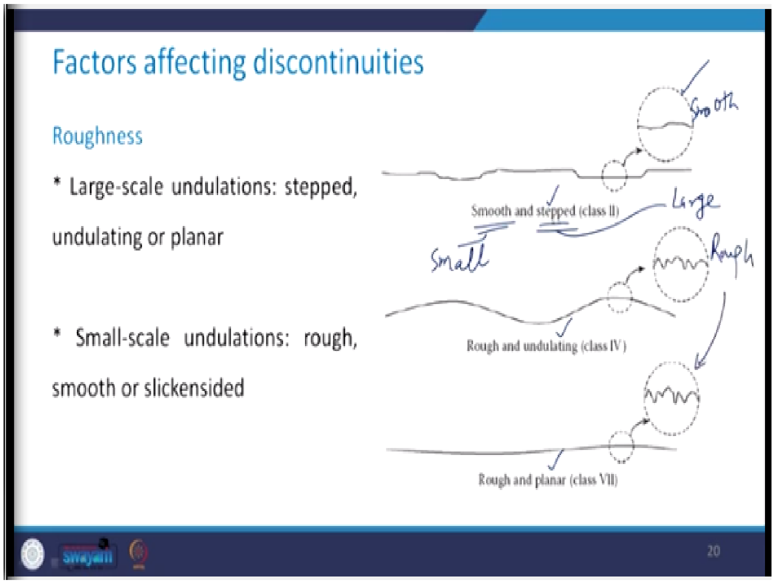

So, when we have the large-scale undulations, these are stepped, undulating or planar. Small scale undulations they are rough, smooth or slicken sided. So, here in this figure, you can see that when I say stepped means this is giving us the idea about the large scale and when I say smooth, this is small scale. And as it is clear from the figure that whether it is stepped or undulating or planar that we can see, we can visualize that just by looking at that figure.

But the small-scale unevenness cannot be seen until and unless you zoom a small portion out or take the close up of that, then only you will be able to get. Like here you see, this is more or less smooth and here this is rough and this is also rough.

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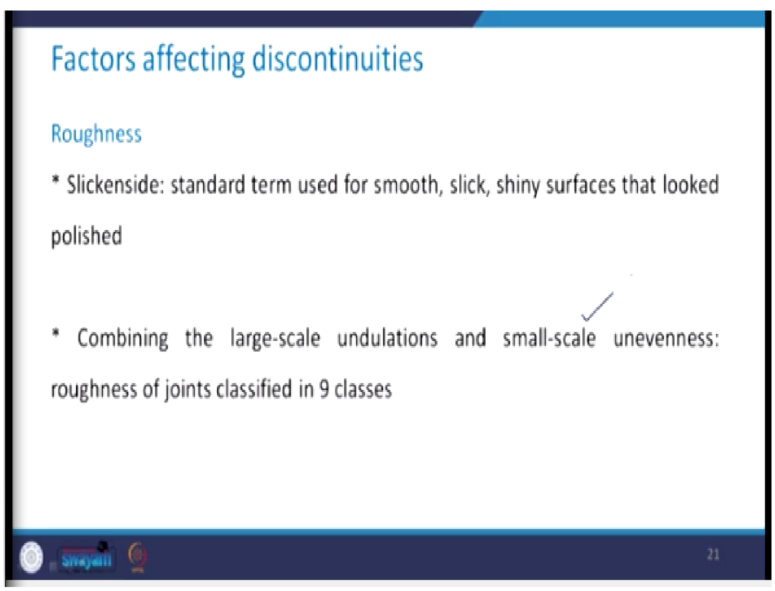

Slickenside means it is the standard term which will be used for smooth, slick, shiny surfaces that looked polished. So, in the rock mass classification system when we will be assigning the ratings, so there will be many tables, where these terms will be used quite often. So, it is better that you understand these terms right at this moment. Now combining the large-scale undulations and small-scale unevenness, roughness of the joints, they are classified in nine classes.

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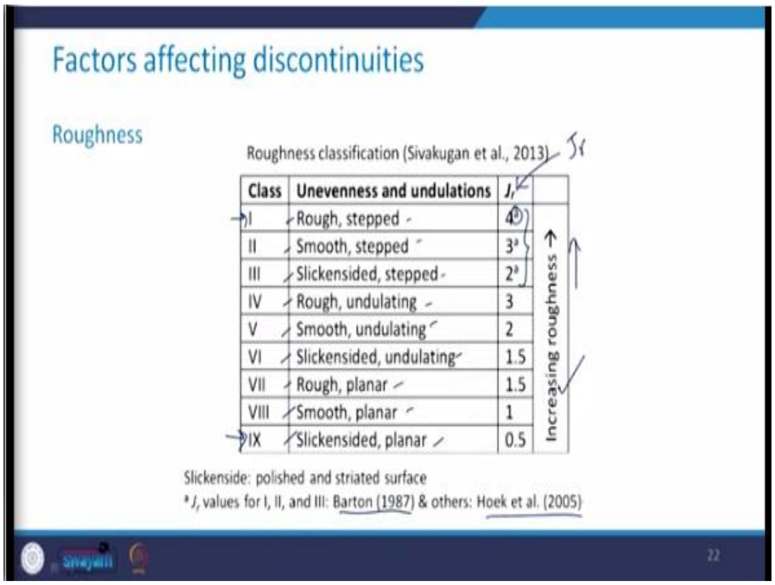

Have a look here, this is roughness is represented as J_r. So, in this fashion in this direction, it is the increasing roughness. So, you have nine classes I to IX, and then you have all the combinations. So, you see the first one is all 3 stepped but small-scale unevenness is very rough, smooth, slicken sided. Similarly, the next 3 are for undulating large scale roughness and again you have the 3-category rough, smooth and slicken sided.

And similarly for the planar you have a rough, smooth and slicken sided. So, the rating has been given like 0.51 and it is going up to 4. So, wherever the superscript *a* is there like for these 3 values these are defined this roughness was defined by Barton and rest other by Hoek et al. in 2005. We will discuss these in detail, then we discuss the classification of the rock mass.

Now the large-scale surface undulations, they have greater influence on the roughness as compared to the small-scale unevenness. Take a look at this table.

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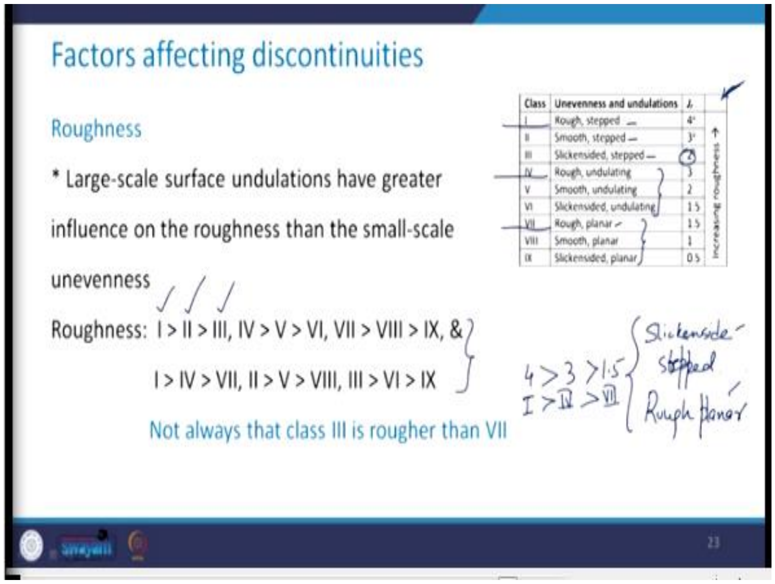

If you take same level of large-scale roughness, that means stepped and stepped, then you will realize that class I is rougher as compared to class II is rougher as compared to class III. So, the rating for the roughness for class III is minimum here it is 2 as compared to for the class I which is 4. Similarly, if you compare in the second category of the large-scale roughness that is undulating the same pattern you will see and likewise you will have the same thing for planar.

Now compare on the basis of small-scale unevenness like rough stepped, rough undulating and rough planar. That means for all these 3, the small-scale unevenness is the same but large-scale roughness is different, one is stepped, another one is undulating and third one is planar. So, let us see, this is 4 which is more than 3 which is more than 1.5. So, this is for I class which is IV and that is VI, so likewise you can compare the relative roughness of these classes.

Although we can be sure about the relative roughnesses of these, but one thing is there, take a note here that class III will not always be rougher than class VII, so what is class III? This is slicken-sided, stepped, so slicken sided and stepped and class VII is rough planar. So, we cannot say for sure the relative roughness corresponding to these 2 categories. If you are keeping large scale roughness same and you are comparing with respect to small scale unevenness, then you can find out a trend in all the categories and other way round also is true.

But such cases we cannot say that class III is always rougher than class VII. The important factor governing the shear strength of the joint, especially when the discontinuity is undisplaced or interlocked. So, we need to be careful about this roughness. This roughness is less important in case of the displaced joints or infilled joints or joints with no interlocking.

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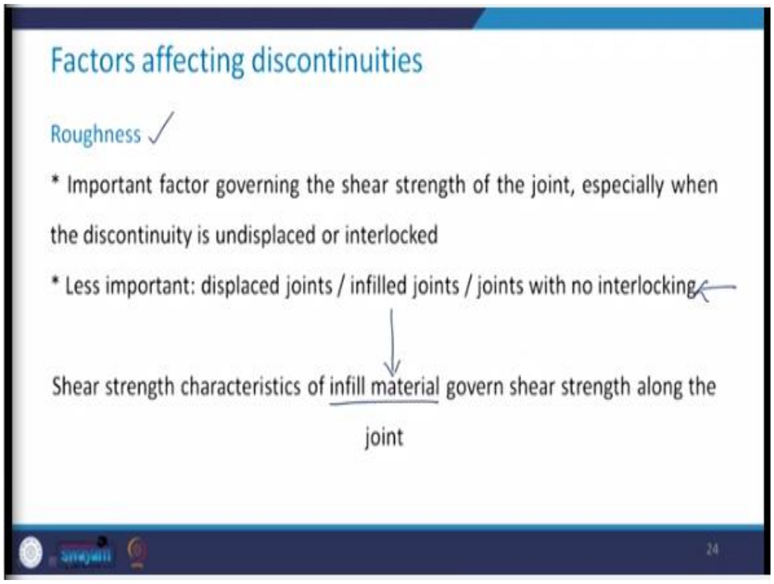

And therefore, the shear strength characteristic of infill material governs the shear strength along the joints. So, when you have infill joints or this category of the joint then it is the characteristic of the infill material that govern the shear strength not the roughness of the discontinuity. So, this is what that I wanted to discuss with you. So, first we discussed about some of the characteristic of the rock mass as against intact rock.

And then we had discussion on few factors affecting the discontinuities. You have seen that there are many other factors which will influence the discontinuities. So, we will discuss about these in detail in the next class. Thank you very much.