Rock Engineering
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Module - 5
Lecture - 21
Classification of Rock Mass: Rock Mass Rating (RMR) - 1

Hello everyone. In the previous class, we discussed about the classification of rock mass and I told you that what all are the factors that affect the discontinuities. So, today's class, we will learn about the first classification system pertaining to rock masses, which is rock mass rating. In short, we call that as RMR. Before I discuss about this classification system, first we will have some idea about the rock mass, intact rock; general discussion; and then we will start with the classification system.

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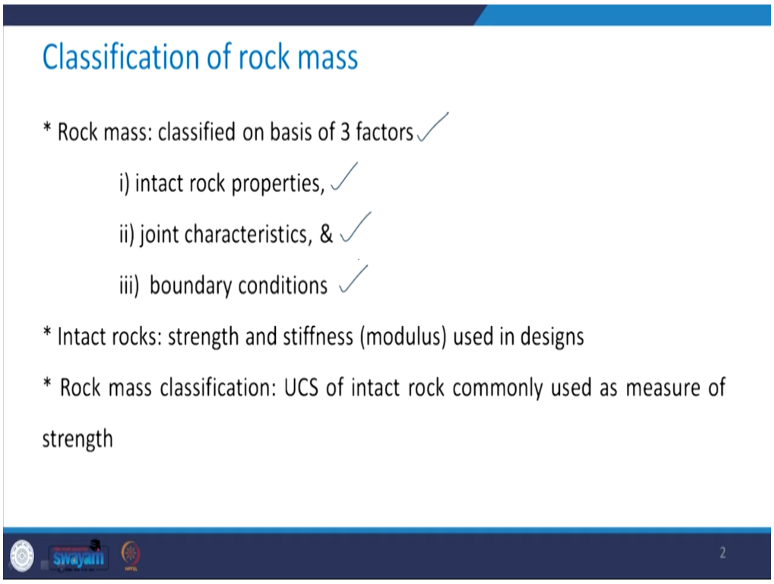

So, rock mass; they are classified on the basis of 3 factors which are intact rock properties, joint characteristics and the boundary conditions. You know that, as far as intact rocks are concerned, their strength and stiffness or modulus; they are used in design. How to determine these? We have seen all these things in detail. Coming to the second point, that is joint characteristics.

We have seen in earlier two classes that what all are the various factors which affect discontinuities and what are those characteristic which define any discontinuity and how these can be determined. So, in the previous class; you should recall that we had one table towards the end of the class, where I gave you the idea about various methods to determine those characteristic.

Third one is the boundary condition, which will be different for different structures. As far as intact rocks and its strength is concerned, in rock mass qualification, it is the unconfined compressive strength of the rock which is commonly used as a measure of intact rock strength. Stability of the jointed rock mass: That is significantly influenced by the frictional characteristic along the joint between the adjacent blocks.

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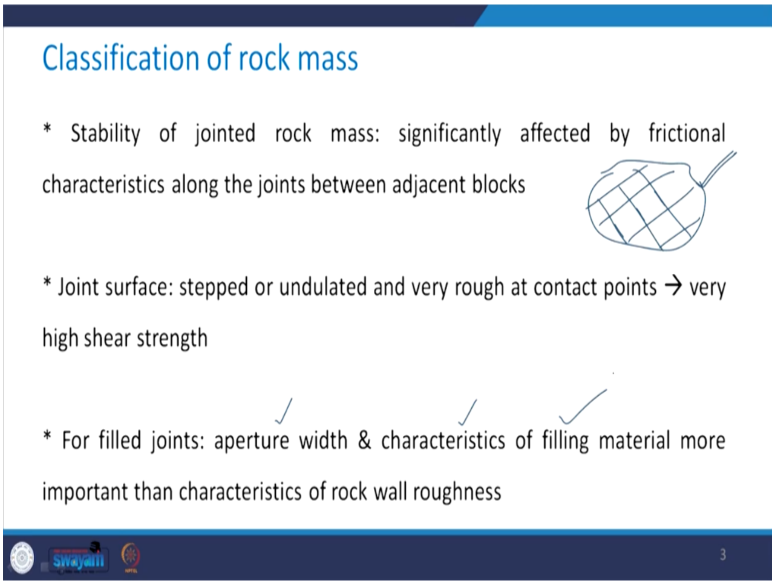

So, let us say that you have this rock mass and these are some, say joint sets, which are there. So, the stability of this whole rock mass, that would be significantly influenced by the frictional characteristic along these joints, which are there between the adjacent blocks. We have also seen that the joint surfaces, they had 2 types of roughness profile. One was large-scale roughness, another was small scale unevenness. So, that also influences its stability.

So, joint surface, whether it is stepped or undulated and very rough at contact point, they have very high shear strength. As far as filled joints are concerned, it is not the roughness which will be important for such joints, but the aperture width and the characteristic of filling material which will be more important as compared to the rock wall roughness. Coming to the third category, which is used mainly for the classification of the rock mass includes boundary conditions.

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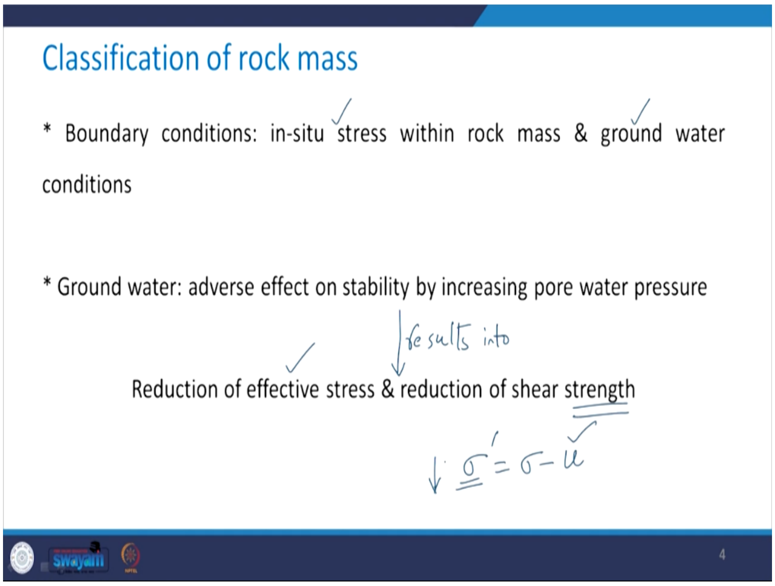

This has in-situ stresses within the rock mass and groundwater conditions. So, in-situ stresses and groundwater condition, they define the boundary conditions for a rock mass. As far as groundwater is concerned, it has adverse effect on the stability. Why? Because, when the groundwater is present, that increases the pore water pressure, which in result; or this results into the reduction of effective stress and therefore the reduction of shear strength.

You know that we always represent these strength characteristic with respect to the effective stress. And you know that the effective stress is the total stress minus the pore water pressure from your soil mechanics background. So, the same effective stress principle is applicable here. So, the moment this quantity, that is the pore water pressure increases, this effective stress, it reduces. Therefore, you see a reduction in the shear strength.

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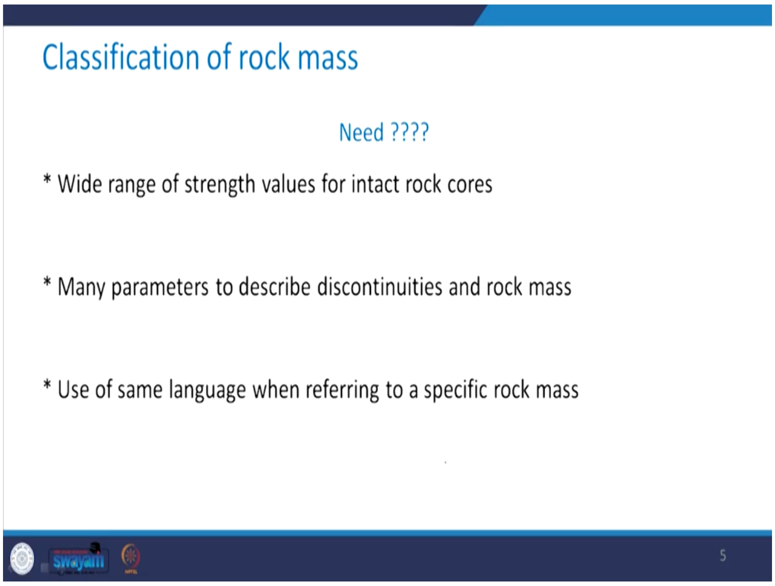

The next question which should come in our mind that what is the need for the classification of the rock mass. Answer is given here in this slide. That is, there is a wide range of strength values for intact rock cores. So, based upon that, we need to classify the rock mass and not based upon only the mineralogical composition. The second aspect includes that there are many parameters describing discontinuities and the rock mass. And therefore, we need to consider all those parameters. And for that purpose, we need to classify the rock mass.

Lastly, we need to have the same language when we refer to a specific rock mass. So, until and unless we have some kind of a language, we will not be able to communicate with each other while mentioning or referring about a particular rock mass. So, these are the reasons that one needs to go for the classification of rock mass. Now, the common rock mass classification systems include rock mass rating system;

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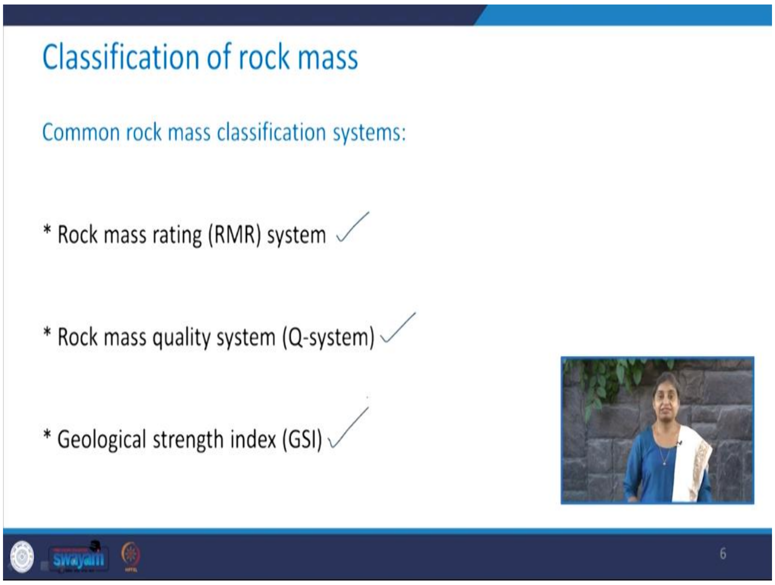

This is also called as RMR system. Then rock mass quality system or in short, it is called as Q-system. And the third one is geological strength index, that is GSI. So, today we will learn about the first classification system for the rock mass, which is rock mass rating system. This system was initially developed by Bieniawski at CSIR on the basis of his experience in shallow tunnels in sedimentary rocks.

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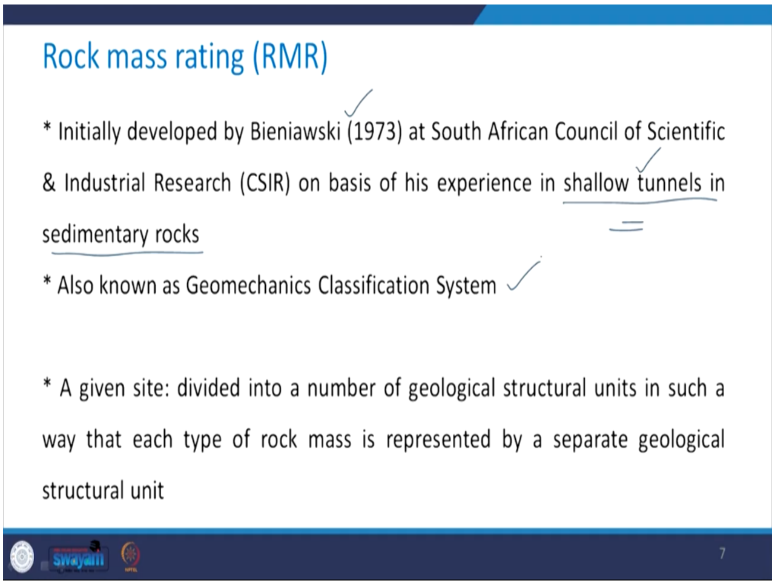

Very important. Why this is very important? Because, when this system was developed, lot many studies were conducted on shallow tunnels in sedimentary rocks. And on basis of those studies only, this system was developed. So, if we want to apply this system to other class of rock or to any other structure; when I say we want to apply it to let us say igneous or metamorphic rock; or let us say I want to apply it to the dam foundation or slope stability analysis; we need to be very careful as far as the application in those areas are concerned.

Because, this classification system was developed based upon the experience in shallow tunnels in the sedimentary rocks. So, one of the limitation of this classification system is, that is more suitable to this condition. This is also known as geomechanics classification system. What is done in this case is: At any given site, we need to divide the whole site into a number of geological structural units in such a manner that each type of rock mass is represented by a separate geological structural unit.

Now, say that you want to go for the construction of a tunnel. And the stretch for the tunnel is say few kilometers. So, I have to traverse through that whole stretch in order to identify different geological structural units. Now, how should we do that? We need to have some kind of an exposed surface. We need to carry out lot of visual inspection in terms of colour; in terms of joints; in terms of joint sets.

Wherever along that stretch, there is a change in any of these geological structural units, there only you have to take that as one unit. And the next one, you should assign as the other unit.

Why we need to do that is, so that we do not miss any representative data all along the stretch of the tunnel. There are six parameters which are to be determined for each structural unit.

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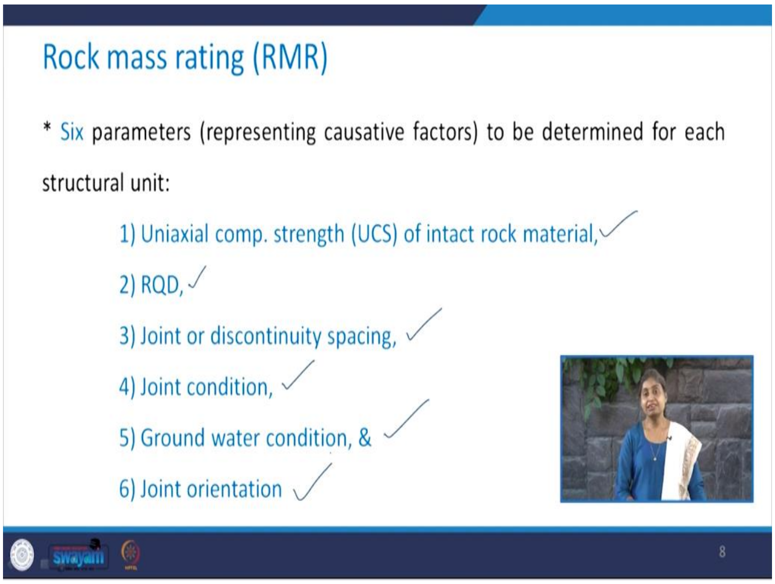

So, once we have identified the structural units at the site all along the stretch of the structure, say in this case tunnel. Then, for each of these structural unit, you have to take some of these parameters into account. That is, the first one is UCS of the intact rock material; then RQD; joint or discontinuity spacing; condition of the joint; groundwater condition; and the last one is joint orientation.

Let us see one by one, how to assign the rating to each one of these parameters in order to determine the rock mass rating. What is done in this case or in this classification system is, all these 6 parameters they are assigned a rating. So, the RMR is obtained out of these 6 ratings. The first 5 parameter and their ratings, they are added. And their maximum value of this addition can go up to 100.

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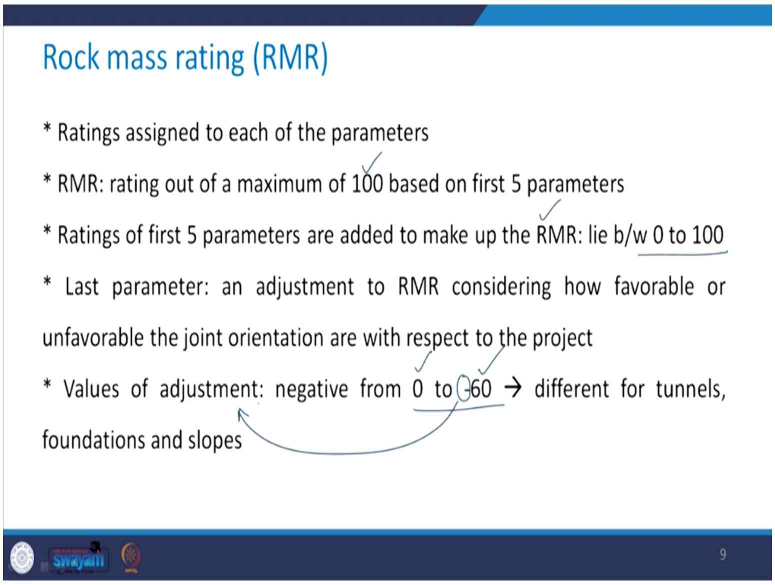

So, the rating of first parameters which are added to have the RMR value; and this lie between 0 to 100. The last parameter, which is the joint orientation; it is an adjustment to RMR considering how favourable or unfavourable the joint orientation are with respect to the project. Now, the value of these adjustments, they are negative and vary from 0 to 60. Again, they are negative. So, they are varying from 0 to -60.

This negative is for this adjustment; different for tunnels, foundations and slopes. The values of the adjustment, they are negative and they vary from 0 to -60. And these values are different in case of tunnels, foundations and slopes. So, we have the adjustment values different for each of these structures. Coming to the strength of the intact rock that is quantified by UCS or point load strength index. Now you know how to determine these 2 things, that is UCS and point load strength index.

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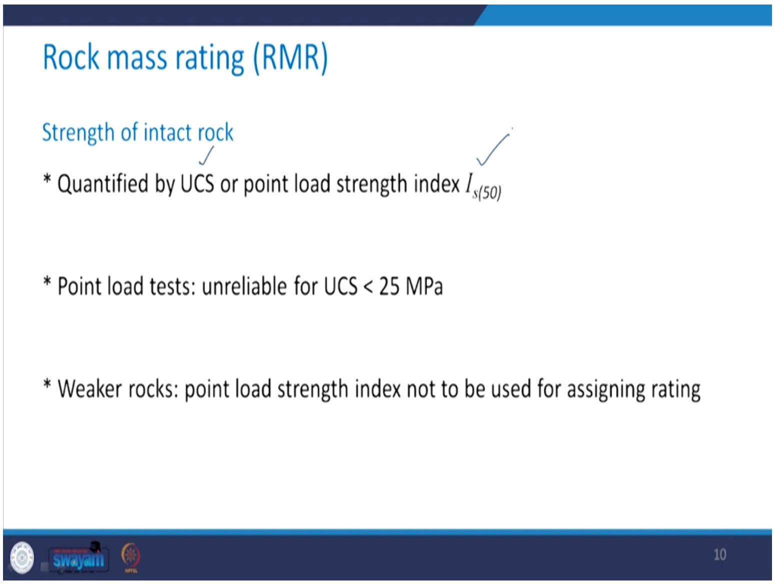

Point load test results: They are unreliable for UCS less than 25 MPa, for the assignment of any rating to the strength of intact rock. For weaker rocks, point load strength index should not be used for assigning the rating. So, how this should be done? There, we have to rely on the value of UCS.

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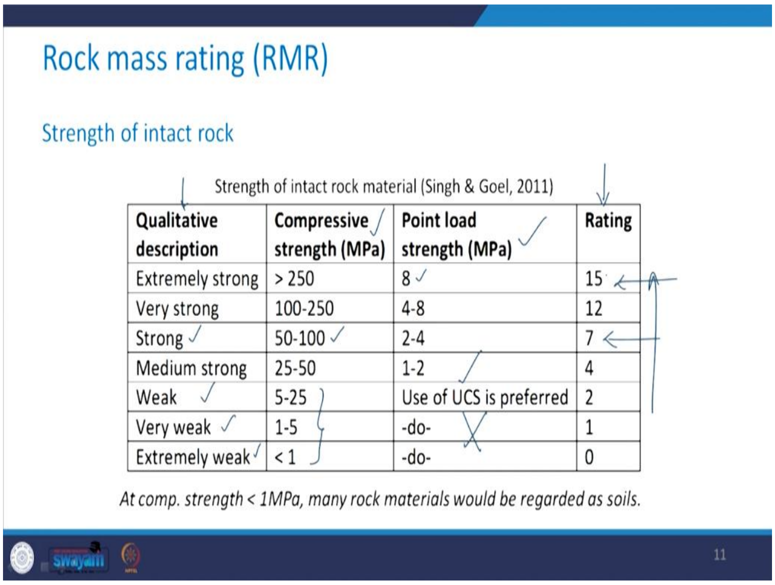

Qualitative description	Compressive strength (MPa)	Point load strength (MPa)	Rating
Extremely strong	> 250	8	15
Very strong	100-250	4-8	12
Strong	50-100	2-4	7
Medium strong	25-50	1-2	4
Weak	5-25	Use of UCS is preferred	2
Very weak	1-5	-do-	1
Extremely weak	< 1	-do-	0

Table is given, where the first column gives you the idea about the qualitative description. Second one is for the compressive strength. Third column gives the idea about the corresponding point load strength in MPa. And then finally, the last column gives you the rating. Now, if the UCS value of the intact rock is more than 250, the rock is called as extremely strong.

And its corresponding value of point load strength will be 8; and the rating which is assigned is 15. Similarly, if you have let us say the compressive strength of 75 MPa. So, 75 MPa will lie in this category, which is strong; and it will have the rating of 7. Now, as I mentioned that in this case of the poor rock or weak rocks, it is the use of UCS, which is preferred rather than the point load strength.

In the last 3 categories, that is weak, very weak and extremely weak, one must rely on these UCS value and should not go for the point load strength. Now, you can see that, as the quality of the rock gets better, the rating towards RMR with respect to the strength of the intact rock also increases. So, it is 0 for extremely weak and 15 for extremely strong. Any compressive strength less than 1 MPa; many rock materials; they would be regarded as soils.

So, accordingly, you need to assign the rating as 0 for this case. Coming to the next parameter which is the rock quality designation, RQD. This is determined from rock cores or volumetric joint count. And we have seen in some of the previous classes how to determine these. So, once we know the value of RQD, we can refer to this table in order to assign the rating for RQD in the RMR system. So, when you have the qualitative description of excellent, the corresponding value of RQD is 90 to 100%.

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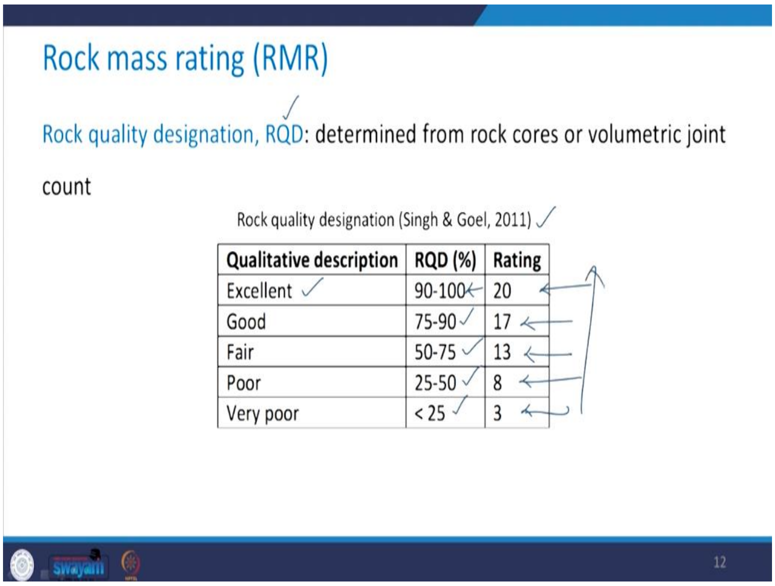

And the rating which is assigned is 20. 70 to 90% RQD, rating is 17; 50 to 75, 13; 25 to 50 is 8; and then, if the RQD is less than 25%, then the rating is 3. So, as it was there in case of the UCS, similarly, here in case of RQD, as the quality gets better, the rating will be larger. So, it increases in this direction.

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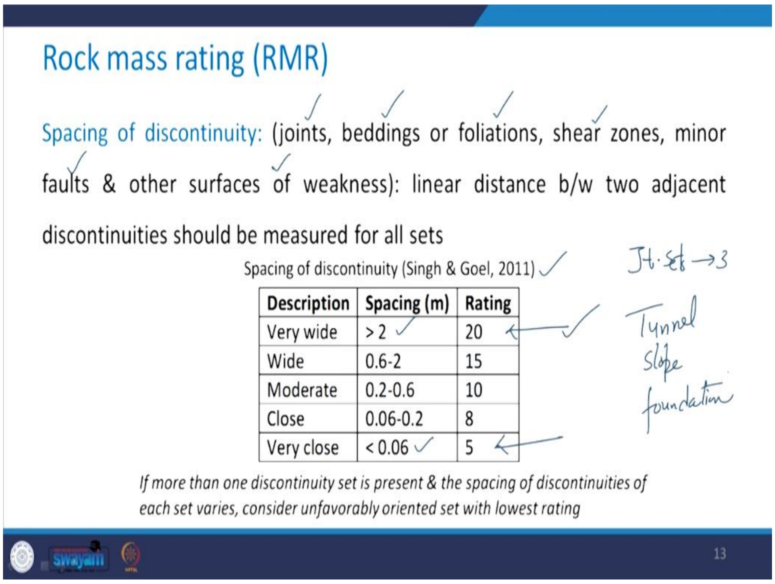

Next, parameter includes spacing of the discontinuities. You know that these discontinuities can be joints; bedding planes; foliations; shear zones; minor faults; or any other surface of the weakness. How we define the spacing of discontinuities? That is a linear distance between two adjacent discontinuities that should be measured for all the joint sets. So, let us say, at any particular structural unit, if there are three joint sets, you have to measure the spacing for each of these three sets.

Based upon the spacing of the discontinuity, the rating is assigned as per this table. For very wide spacing, which is more than 2m, the rating is 20. And if it is very close, that is less than 0.06m, it is 5. What do we understand if the spacing of the discontinuity is more? That means that the quality of that rock mass is better. So, that is why you have more rating for wider spaced joints or discontinuities.

The question is; as I mentioned that let us say that there are 3 joint sets. The question is: Which one should we take towards the calculation of this RMR? Which one should we consider? In that case, we should see that whichever joint set is unfavourably oriented towards that structure, whether it is tunnel, slope or foundations. So, the most critical oriented joint set or the discontinuity set should be considered towards the calculation of RMR.

And rating corresponding to that critical joint set should be given while calculating the value of RMR. Spacing of the discontinuities: So, I mentioned to you that when you have the wider joint spacing, lesser will be the deformation within the rock mass. And therefore, you have high rating.

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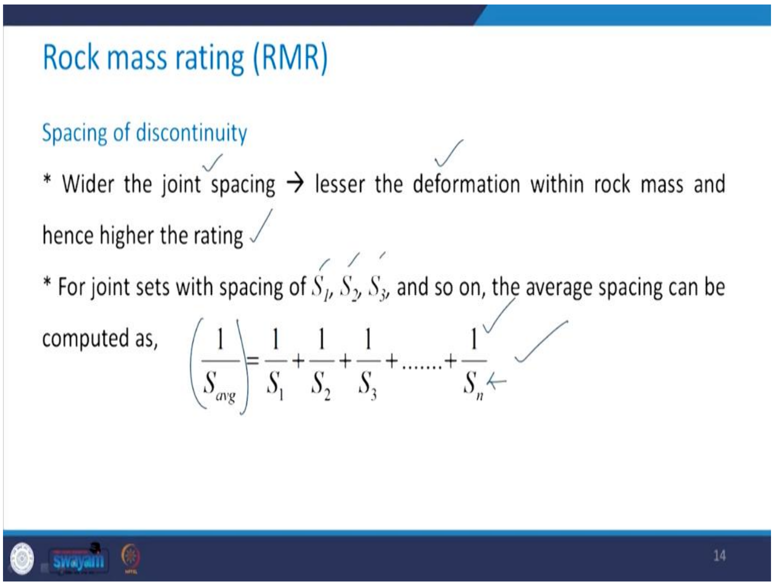

Say you have the joint sets with spacing of say S_1, S_2, S_3 and so on. Let us say n joint sets till S_n. The average spacing can be computed as using this expression. That is 1 upon S_{avg} is equal to (1 upon S_1) + (1 upon S_2) and so on up to (1 upon S_n).

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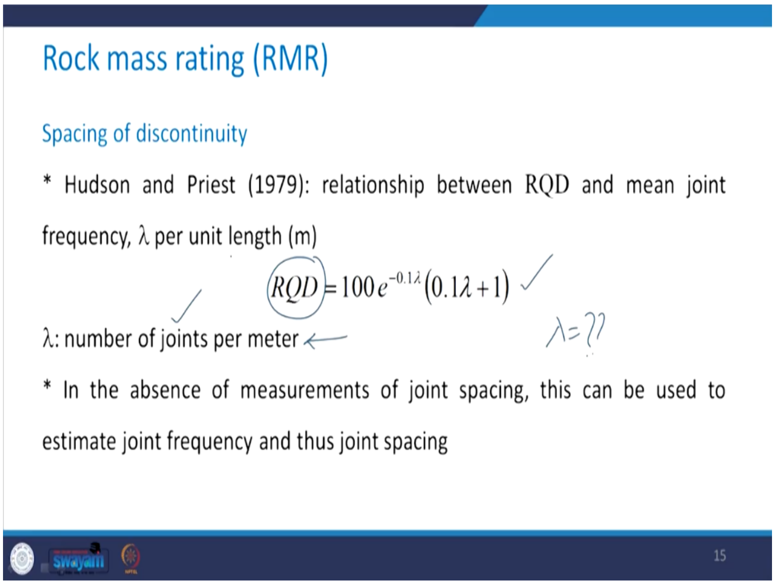
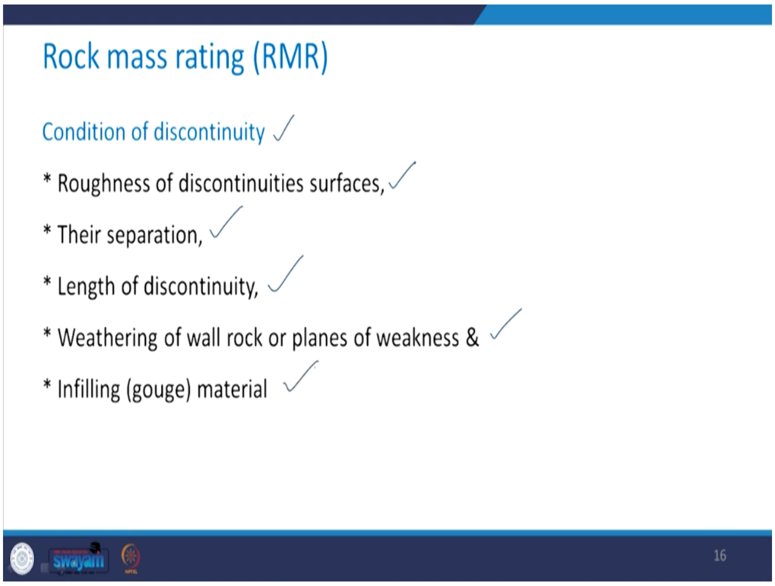


Hudson and Priest, in 1979, they gave a relationship between RQD and mean joint frequency,

$$RQD = 100e^{-0.1\lambda}(0.1\lambda + 1)$$

lambda (λ), which is per unit length. So, this length here is in metre. So, λ is defined as number of joints per metre. So, the RQD can be determined using this expression. So, in the absence of any measurement of the joint spacing, this expression can be used to estimate the joint frequency and therefore the joint spacing.

So, you know that you will have the RQD with you. And you can use this expression and find out the value of lambda. Just in case if you do not have any measurement of the joint spacing and this lambda is defined as a number of joints per metre. So, in one metre length, you know how many number of joints are there. So, therefore, you can divide that one metre by these number of joints. And that will give you the spacing of the discontinuity. **(Refer Slide Time: 23:46)**



Coming to the next parameter, which is the condition of the discontinuity. These include the roughness of discontinuity surfaces; their separation; length of the discontinuity; weathering of wall rock or planes of weakness; and the infilling material, which can also be called as gouge material..

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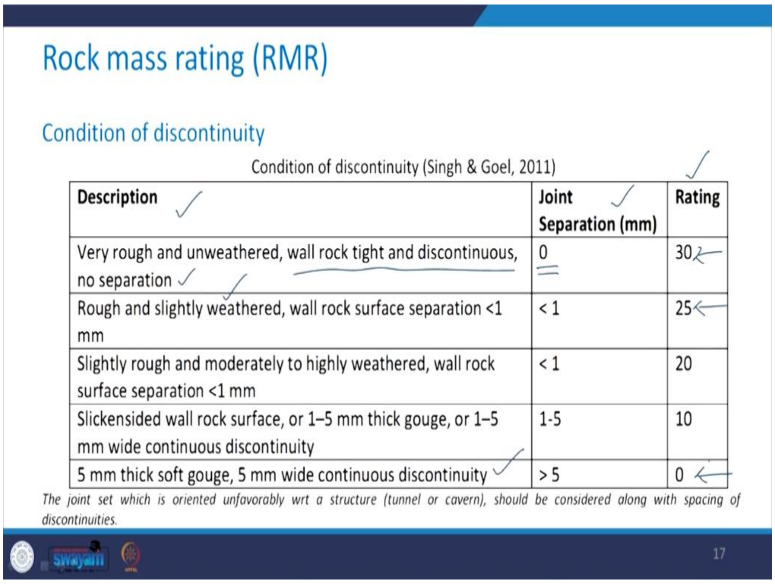

Rock mass rating (RMR)

Condition of discontinuity

Condition of discontinuity (Singh & Goel, 2011)

Description	Joint Separation (mm)	Rating
Very rough and unweathered, wall rock tight and discontinuous, no separation	0	30
Rough and slightly weathered, wall rock surface separation <1 mm	< 1	25
Slightly rough and moderately to highly weathered, wall rock surface separation <1 mm	< 1	20
Slickensided wall rock surface, or 1–5 mm thick gouge, or 1–5 mm wide continuous discontinuity	1-5	10
5 mm thick soft gouge, 5 mm wide continuous discontinuity	> 5	0

The joint set which is oriented unfavorably wrt a structure (tunnel or cavern), should be considered along with spacing of discontinuities.

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You will be able to realize that why there are many factors as far as condition of discontinuity is concerned, which one needs to keep in mind. See the first column gives the description. Second one deals with the joint separation. And third one finally assigns the corresponding rating. In case if you have very rough and unweathered, wall rock tight and discontinuous and there is no separation, means it is here a 0; rating is 30.

Then, rough and slightly weathered, wall rock separation is not 0 but less than 1mm, then the rating reduces, which becomes 25. So, based upon the parameters which I just mentioned to you, you can refer to this table and assign the rating. So, take a look here, that 5mm thick soft gouge; if this is the situation, then the rating is 0.

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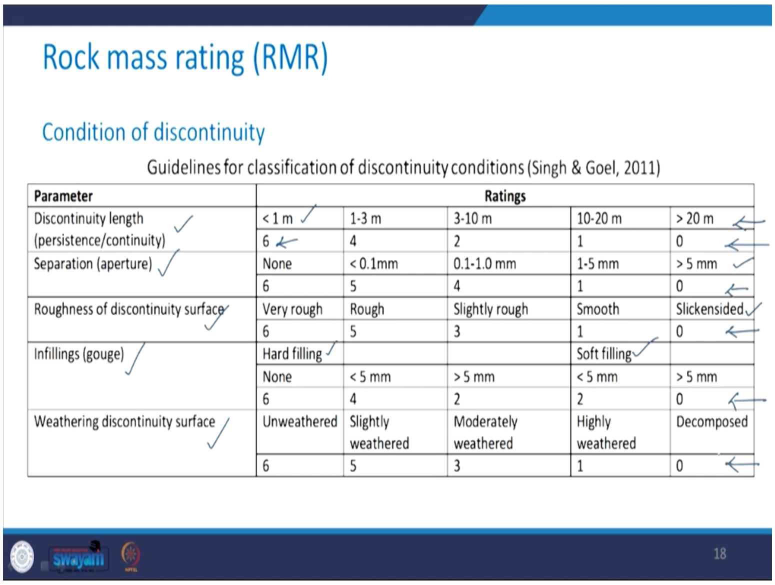

Rock mass rating (RMR)

Condition of discontinuity

Guidelines for classification of discontinuity conditions (Singh & Goel, 2011)

Parameter	Ratings				
Discontinuity length (persistence/continuity)	< 1 m	1-3 m	3-10 m	10-20 m	> 20 m
	6	4	2	1	0
Separation (aperture)	None	< 0.1mm	0.1-1.0 mm	1-5 mm	> 5 mm
	6	5	4	1	0
Roughness of discontinuity surface	Very rough	Rough	Slightly rough	Smooth	Slickensided
	6	5	3	1	0
Infillings (gouge)	Hard filling			Soft filling	
	None	< 5 mm	> 5 mm	< 5 mm	> 5 mm
	6	4	2	2	0
Weathering discontinuity surface	Unweathered	Slightly weathered	Moderately weathered	Highly weathered	Decomposed
	6	5	3	1	0

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If we have let us say more detail about the condition of the discontinuity; we have persistence, aperture; all these things, we discussed in the previous class. So, if we have all those things in detail, then we can refer to this table where you have all these parameters. That is discontinuity length, which can be also defined as persistence; aperture; roughness; infilling or gouge material; and weathering or discontinuity surface.

So, accordingly, this table gives you some of these parameters in the quantitative manner and accordingly you can assign the rating. So, let us say that the discontinuity length is less than 1m, it will have the rating of 6. So, the first row is giving you the value of the parameter and second row is giving you the rating. Likewise, it is there for all the rows. So, this is the parameter; this is the rating; and likewise. So, in case of the infilling, when you have hard filling or you have the soft filling, accordingly you need to assign the rating.

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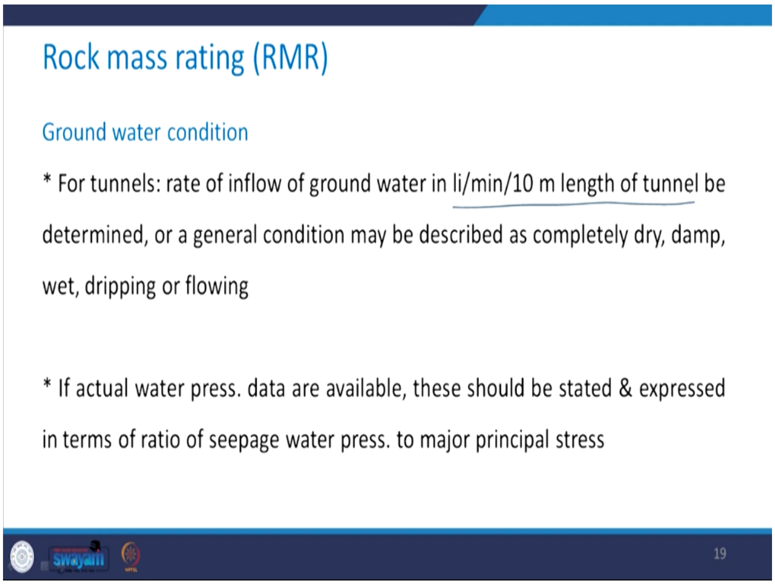

The last parameter towards the calculation of rock mass rating is groundwater condition. For tunnels, it is the rate of inflow of groundwater in l/m per 10m length of the tunnel. This should be determined; or, a general condition may be described as whether it is completely dry, damp, wet, dripping or flowing. If the actual water pressure data, they are available, these can be stated and expressed in terms of ratio of seepage water pressure to major principal stress.

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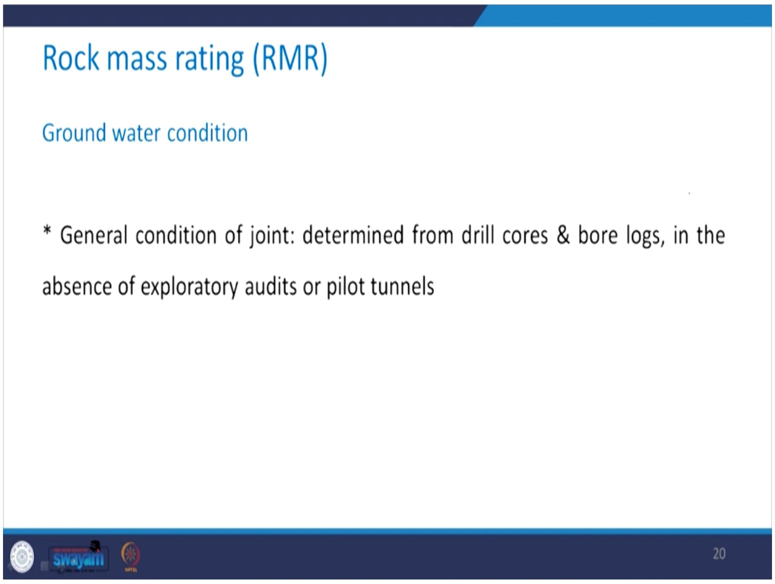

General condition of the joint: It can be determined from the drill cores and bore logs, in the absence of exploratory audits or pilot tunnels.

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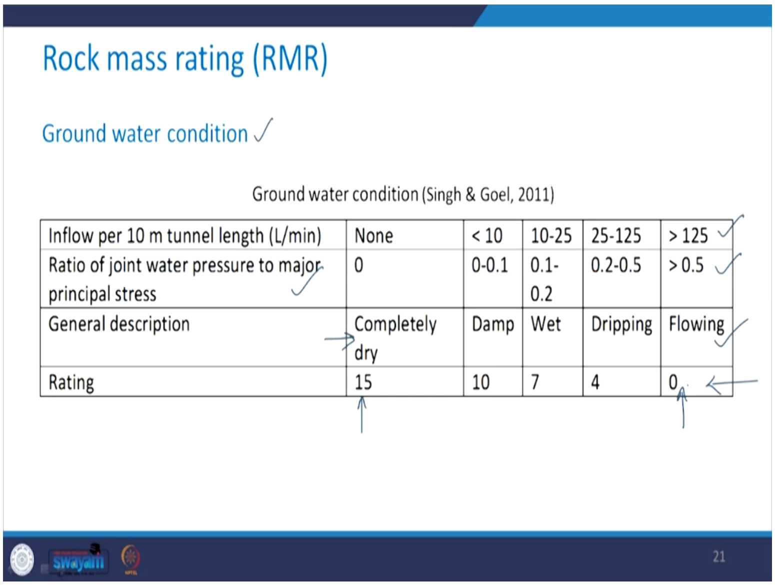

Inflow per 10 m tunnel length (L/min)	None	< 10	10-25	25-125	> 125
Ratio of joint water pressure to major principal stress	0	0-0.1	0.1-0.2	0.2-0.5	> 0.5
General description	Completely dry	Damp	Wet	Dripping	Flowing
Rating	15	10	7	4	0

So, based upon these observation, this table gives the idea about the rating towards groundwater condition. So, you see that, if you have inflow per 10m length, which is in l/min; and then, it can also be represented in terms of ratio of joint water pressure to the major principle stress; and this is the general description. So, either of the 3, you can have the information with you; either this one or this one or this one.

So, accordingly, you assign the rating. So, when the inflow is less, the rating is more; or, when the excavation is towards the dry state, the rating is more. So, you can see here. It is 15 for completely dry case; and it is 0 for flowing case; and somewhere in between, you have damp, wet and dripping general description for the groundwater condition.

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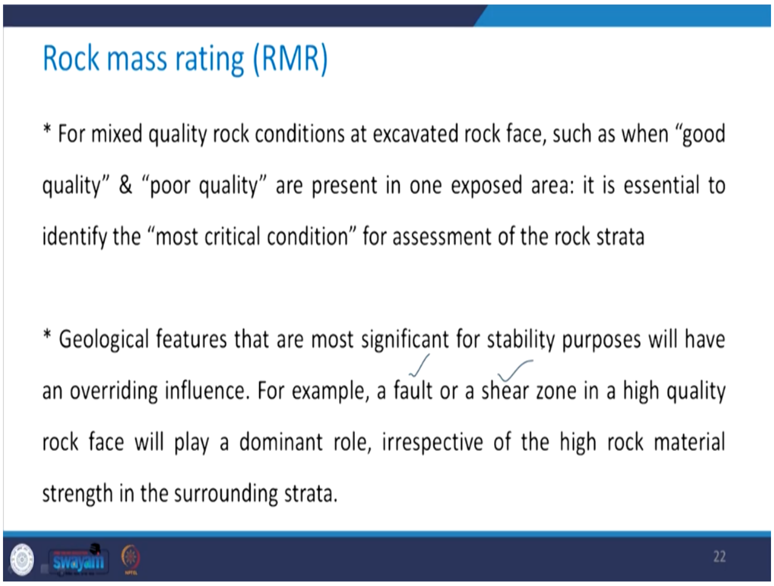

Now, in case if you have the mixed quality rock condition at the excavated rock surface; for example, say there is one exposed area. And there, you have good quality as well as poor quality which is present. So, in that case, it is essential to identify the most critical condition for the assessment of the rock strata. Sometimes it may happen that although the rock material or the intact rock is of very good quality, but then there is an occurrence of say a fault plane.

So, what happens is, although the rock quality is good, so UCS parameter may be very high. But the overall situation with respect to the structure that is going to come up will be very critical because of the presence of that fault zone in that area. So, one needs to be careful about these critical conditions. Geological features that are most important for stability purpose will have an overriding influence.

As I mentioned that in case if you have a fault or a shear zone in a high quality rock face; so, it will not be the quality of the rock, but the presence of the fault or the shear zone will play a deciding role there.

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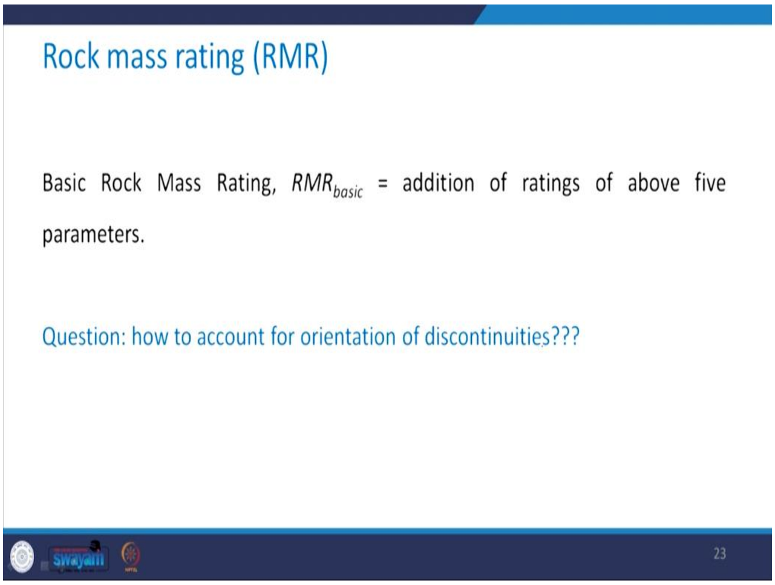

So, the basic rock mass rating can be obtained by addition of ratings of all these 5 parameters as we discussed. The question which is there in front of us is now is: How to account for the orientation of discontinuities? Till now, we have not discussed about the orientation of the discontinuities. So, what we have done is, there are 6 parameters which are to be given a rating towards the calculation of rock mass rating.

We saw that how the first 5 parameters can be assigned the rating based upon the condition there in the field. Add all of these rating and you will get RMR basic. We have not yet considered the orientation of the discontinuities. So, with this question, I finish today's discussion. And in the next class, we will try to find out the answer to this question; and then try to see how we can find out the final value of RMR; and how we can use this RMR for the application purpose. Thank you very much.