Underground Space Technology
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Module No # 01
Lecture No # 05
Basics of Rock Engineering: Classification of Rock Mass - 1

Hello everyone, in the previous class we discussed about the classification of intact rock and I also introduced you the concept of RQD rock quality designation. So, today we will start our discussion on the classification of rock mass. Now the difference I have already told you the difference between rocks and rock masses, they are that when the rocks have the joints or the discontinuity as a whole we call that as rock mass.

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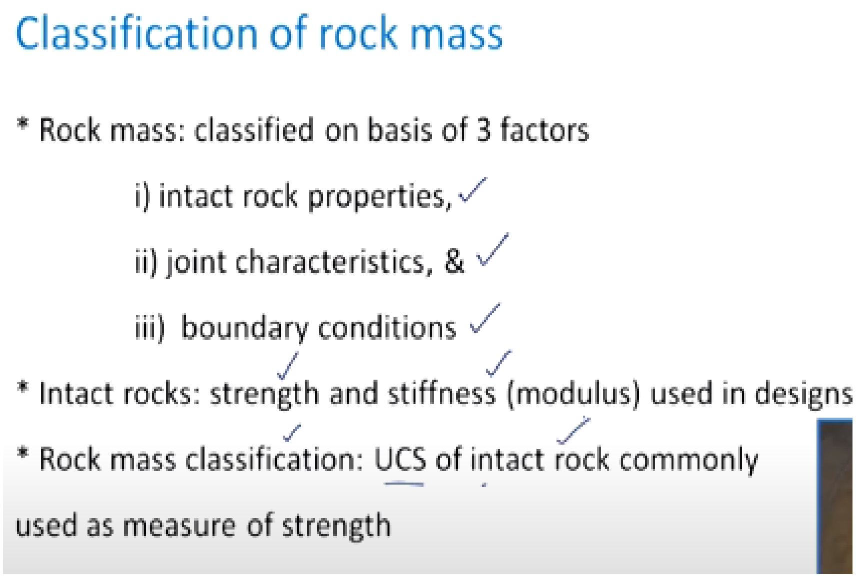

So, let us take a look that how these rock masses they are classified so basically there are 3 factors on basis of which rock masses they are classified. The first one is intact rock properties, joint characteristics and the last one is the boundary conditions. As far as intact rocks are concerned its strength and stiffness are modulus they are used in design. In case of the rock mass classification UCS of the intact rock is commonly used as a measure of strength.

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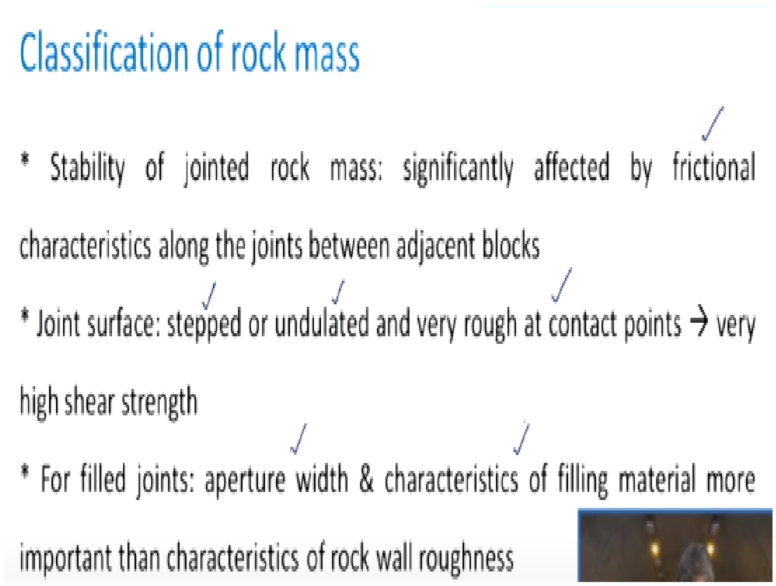

Coming to the stability of the jointed rock mass this is significantly affected by the frictional characteristic along the joints between the adjacent blocks of rock. Now these joint surfaces they can be stepped or undulated and very rough at contact points. So, at contact points what will happen is that you will get very high shear strength. So, for filled joints it is the aperture width and the characteristic of the filling material which become more important as compared to the characteristic of rock wall roughness.

So, in case if you have unfilled joints, it is the rock wall roughness that will govern the strength characteristic of the jointed rock mass. But in case if you have filled joints, it is the aperture width and the characteristic of the filling material becomes more important.

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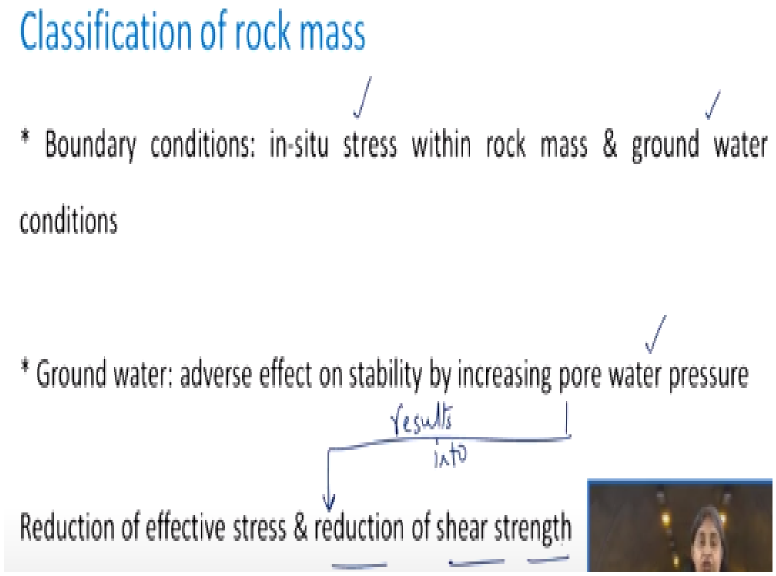

Coming to the boundary conditions these include in-situ stresses within the rock mass and also the groundwater conditions. Now groundwater has adverse effect on the stability of the rock mass why? Because if the groundwater is present it increases; the pore water pressure in the rock mass. And this results into the reduction of effective stress and therefore the reduction of the shear strength. Therefore, it is extremely important for us to know the groundwater condition before we go for the classification of rock mass.

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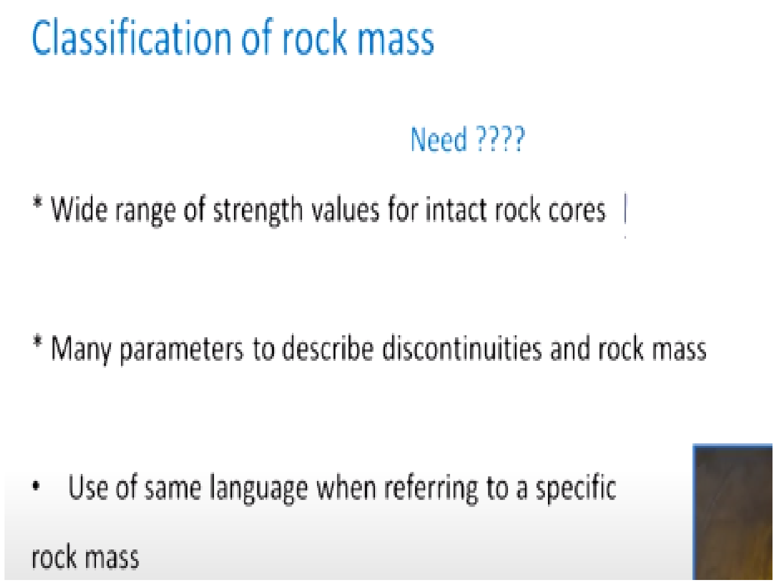

Now the question comes that what is the need for the classification of rock mass? So, here I have listed some of these points such as there are wide ranges of strength values for intact rock course. So, how to classify only on the basis of intact rock cores that becomes always a question mark.

Then many parameters are there which describe discontinuities and rock mass. So, we need to really put them in some different subclasses to make a proper classification which is based on the discontinuities and the other characteristic of the rock mass. Then, let us see all around the world different types of rocks exist now when say 2 geotechnical engineers they are from different countries. So, they should have the same language when they are referring to a particular type of rock mass.

So, to design to define that language that technical language we need to know that what exactly are the; various classification systems of the rock mass. So, these are some of the points that one should have or these points they give us the idea that why should, we need the classification of the rock mass.

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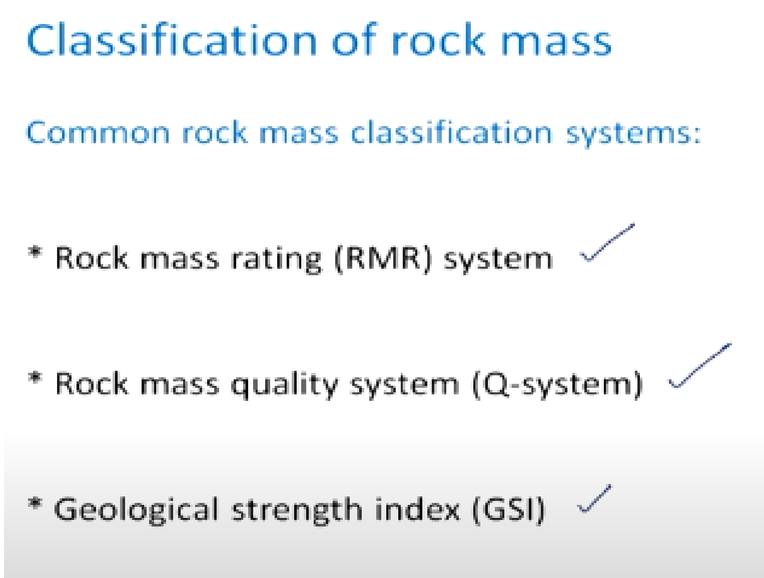

So, different rock mass classification systems are available commonly used systems are rock mass rating system which we call as RMR system, rock mass quality system that is also designated as Q-system and the third one is geological strength index. There are other systems also but we will be focusing only on these 3 that is RMR system, Q-system and GSI.

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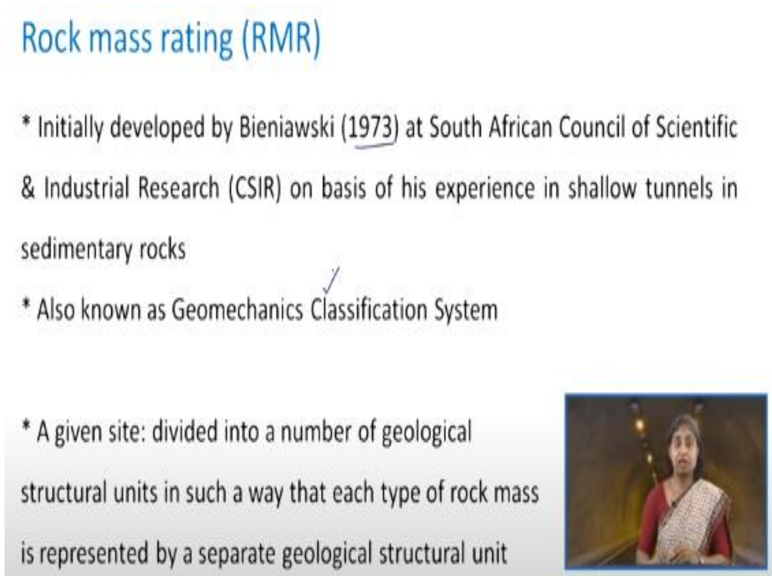

Coming to the first one, that is RMR system, it was initially developed by Bieniawski in 1973 at South African council of scientific and industrial research. On the basis of his vast experience in the areas of shallow tunnels and that too in sedimentary rocks this system is also known as geo-mechanics classification system. Now what is done in this case is that there is a particular site so this site is divided into some number of geological structural units.

And, it is divided in such a way that each type of rock mass is represented by a separate geological structural unit. Now the question is how to identify these different units so let us say you are traversing through that given side and see suddenly you see the there is a change in the color of the rock. So that change may be because of the different mineral composition so what we do is?

We define a geological structural unit there we demarcated that ok here it is the next unit. Similarly, let us say there is a joint pattern that is different there can be the difference in the texture. So, there you have to take a call you have to use your engineering judgment to define these structural units for that particular site.

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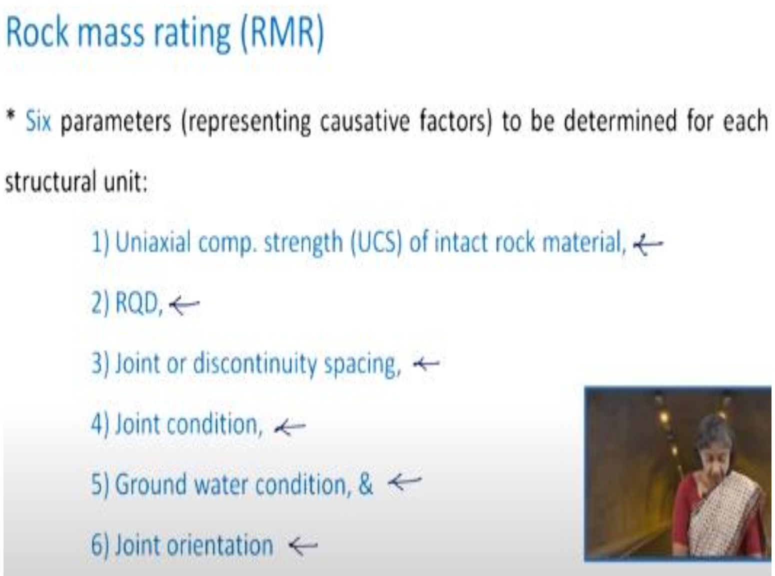

Now, as far as these, rock mass rating system, is concerned basically there are 6 parameters which are to be determined for each structural unit that we have identified at the site. So, these parameters include the UCS of intact rock material, RQD this we saw in the previous class that how we can determine the RQD. Then joint or discontinuity spacing, condition of joint then ground water condition and finally the joint orientation.

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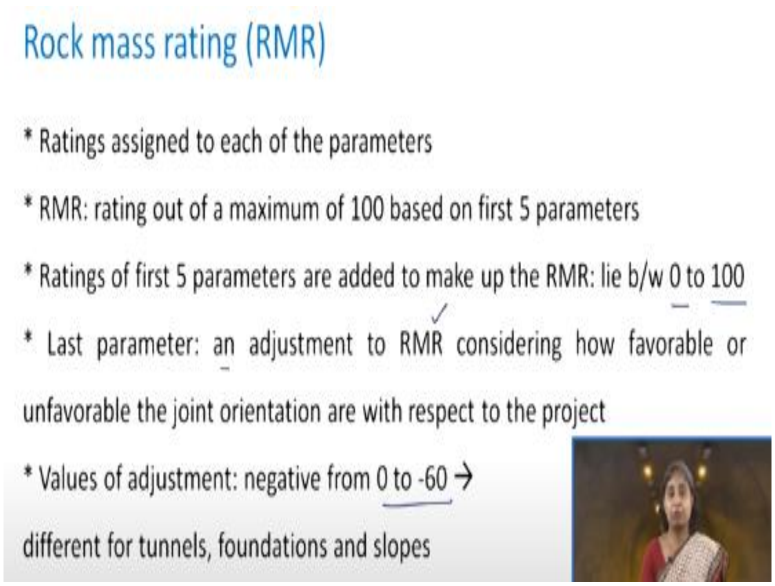

So, what is done in this case is the ratings they are assigned to each of these 6 parameters. So, as far as the first 5 parameters are concerned that means you have to exclude the joint orientation from these parameters. So, you assign the rating to the first 5 and sum these up that will give you the basic value of RMR which will lie between, 0 to 100. The last parameter it is an adjustment to RMR considering how favorable or unfavorable the joint orientations are with respect to the project.

Now, this project may include the construction of tunnel may be the dam foundation or may be related to slopes. So based upon what type of structure it is you have to see whether the joints are favorably oriented or unfavorably oriented with respect to that particular structure. Now the values of this adjustment it is negative and it varies from 0 to -60. As I mentioned that this is going to be dependent on the type of the project. So, it will be different for say tunnels or foundations or slopes.

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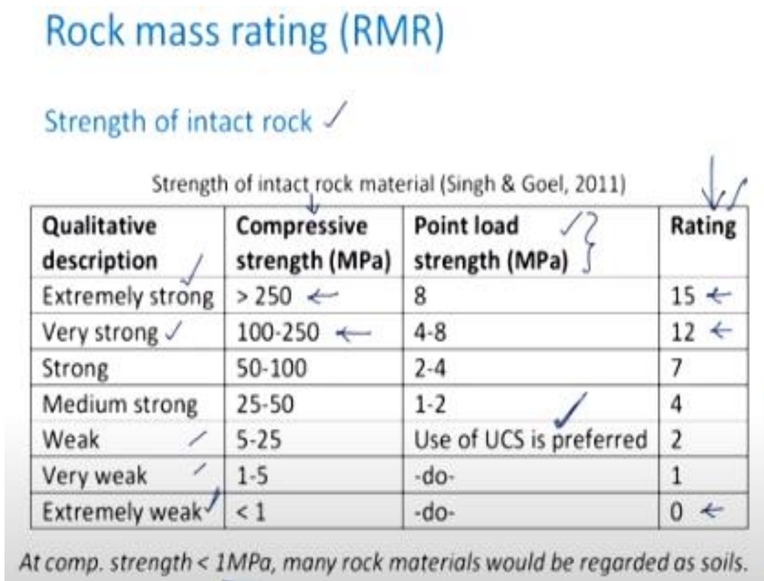

Rock mass rating (RMR)

Strength of intact rock

Strength of intact rock material (Singh & Goel, 2011)

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

At comp. strength < 1MPa, many rock materials would be regarded as soils.

So let us take a look that how do, we assign the ratings to all these 6 parameters so first we will focus on these 5 parameters. We will assign the rating and then we will try to find out that what is the basic value of RMR and then we will make the adjustment for the joint orientation. So here is the table which gives us the idea that how on the basis of UCS of the intact rock how can we assign the rating to the first parameter and how these can be qualitatively described.

So, in case of the first one that is when you have the compressive strength greater than 250 mega pascal the qualitatively you describe the rock as extremely strong and its rating is going to be 15. Similarly, if it has the compressive strength in between 100 to 250 mega pascal it is described as very strong rock and the rating of 12 is assigned. So, likewise if you just go through this table the last one is extremely weak rock which has a compressive strength less than 1 mega pascal and the rating which is assigned is 0.

So, when you have the compressive strength less than one mega pascal many rock materials in such situation would be regarded as the soil. So, you can see that there is a third column for the point load strength index test. So, in case if you are not able to conduct the UCS test then maybe you can conduct point load strength index test. And on basis of their value also you can decide upon the rating with reference to the strength of the intact rock.

However, for weak, very weak and extremely weak category the use of UCS is preferred and we cannot rely on the point load strength in order to decide the rating for the strength of the intact rock. So, once you have the value of UCS for a particular rock when I say rock means, here I am talking about the intact rock. And accordingly, whatever is the value that you obtain from the second column accordingly you pick the rating from this column.

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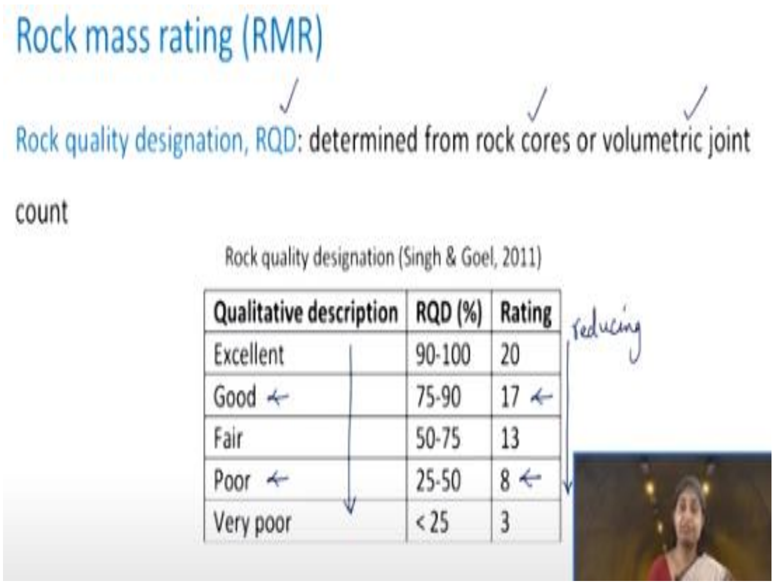

Coming to the second parameter that is rock quality designation RQD and we have seen earlier that we can determine it directly from the rock cores or indirectly from volumetric joint count. And say that RQD works out to be say 85 % so that is the qualitative description for that is going to be good and you can assign the rating of 17 for that type of rock mass. So similarly, if you have poor category then the rating is going to be 8.

So, you see that as the quality of the rock mass degrades in this direction the rating that is assigned to this parameter RQD is also reducing. Similar was the situation that we saw in case of the strength of the intact rock.

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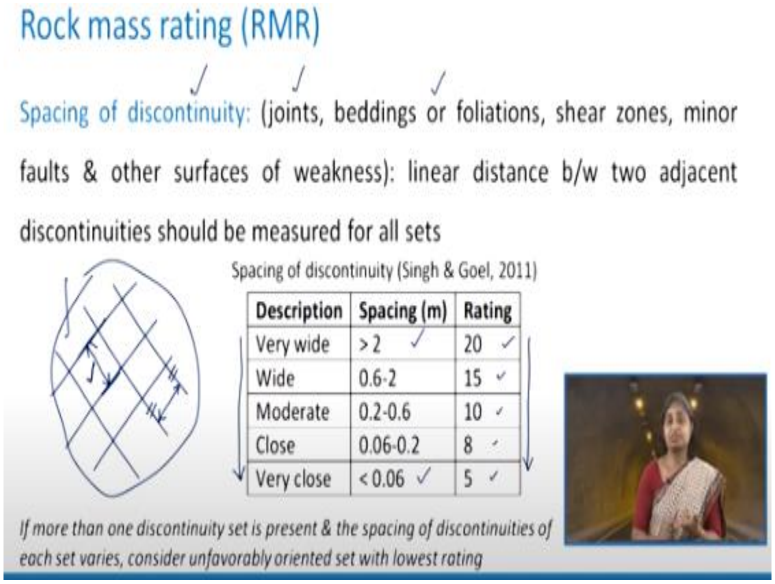

Coming to the third parameter which is the spacing of discontinuity now these, discontinuity they may include joints beddings or foliations there can be the presence of shear zones or minor faults or there can be any other surfaces of weakness. So, the linear distance between 2 adjacent discontinuities should be measured for all the sets. So, let us say that this is the kind of situation say is the rock mass and basically say here you have 2 joint sets so how do we decide that what is the spacing of the discontinuity?

So, what we do is that 2 adjacent discontinuities that is let us say this and this and whatever is the minimum distance between these that is going to be give me the spacing of discontinuity. But then this is going to be for this particular joint set. In case if you have to get the spacing for the other joint set then this distance you should take between these 2 adjacent discontinuities. So based upon the spacing you can assign the rating here.

Now, you see if the spacing is large that means in a particular volume of the rock mass you will have less number of joints and therefore it is going to represent the better quality of the rock mass. So, in this case also as we go from very wide to very close spacing of the discontinuity or larger value of a, spacing to the smaller values of the spacing the rating which is assigned to spacing of discontinuity, it also reduces.

Now in case if you have more than one discontinuity set as I showed you here in this figure then we have to find out the spacing of discontinuity for each and every set. And we have to take the value of the spacing of the discontinuity which is the critical oriented set. That means, that particular discontinuity is most unfavorably oriented with respect to the proposed structure whether it is tunnel? Whether it is foundation or it is the slope related issue.

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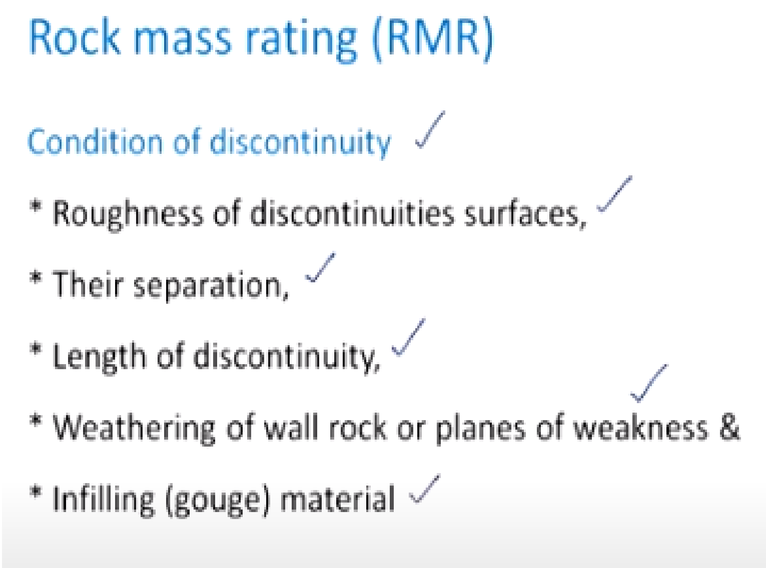

Coming to the next parameter, which is the condition of discontinuity, now these condition of discontinuity, they it may be defined in terms of these parameters. Which have been listed here that is roughness of discontinuity surfaces, their separation, length of discontinuity, then weathering of wall rock or planes of weakness whether there is any infilling or gouge material in the joint. So the property of that infilling material also influences the condition of discontinuity.

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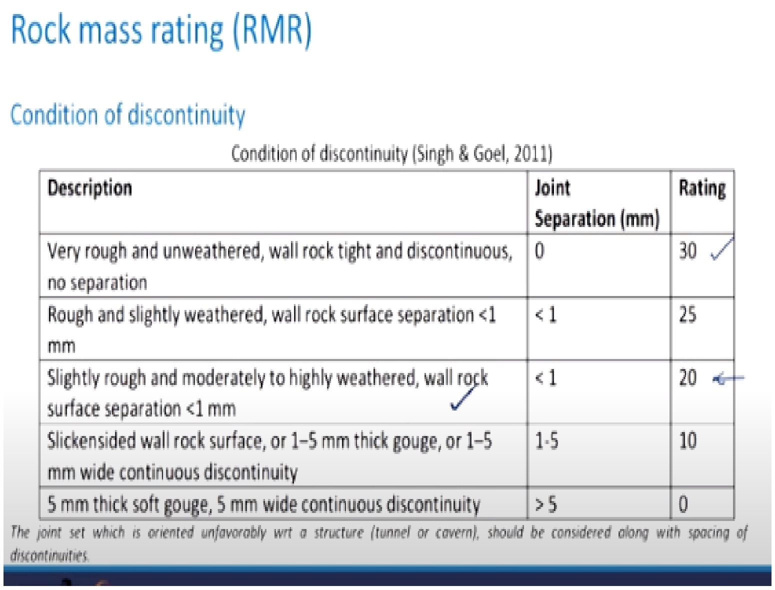

Description	Joint Separation (mm)	Rating
Very rough and unweathered, wall rock tight and discontinuous, no separation	0	30
Rough and slightly weathered, wall rock surface separation <1 mm	< 1	25
Slightly rough and moderately to highly weathered, wall rock surface separation <1 mm	< 1	20
Slickensided 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

So, take a look here this table gives you the idea about the general description. So, in case if you do not have each and every detail of those parameters that I just now discussed with you so if you have the general description of the condition of discontinuity you can use this table and assign the rating. For example, if you have let us say, slightly rough and moderately to highly weathered wall rock surface separation having less than 1 millimeter.

So that means, it is this category so we can pick the rating as 20 again here you can have more than one discontinuity in the rock mass. So, which one do we need to pick? Whichever is most unfavorably oriented with respect to that particular structure that joint we have to consider and its condition only should be assigned the rating to be used for calculating rock mass rating. **(Refer Slide Time: 18:45)**

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

Now in case, if you have all the details available say you have discontinuity length, separation, roughness, infilling and the weathering status. Then you can assign various ratings from this particular table sum them up and find out the overall rating to be assigned to this parameter that is condition of discontinuity.

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Rock mass rating (RMR)

Ground water condition

* For tunnels: rate of inflow of ground water in li/min/10 m length of tunnel be determined, or a general condition may be described as completely dry, damp, wet, dripping or flowing

* If actual water press. data are available, these should be stated & expressed in terms of ratio of seepage water press. to major principal stress

Coming to the fifth one, that is ground water condition for the projects related to tunnels rate of inflow of groundwater in litter per minute per 10-meter length of the tunnel should be determined. If we are not able to determine this then maybe we can describe a general condition in terms of say as completely dry or damp wet dripping or flowing. So, based upon this we need to assign the rating for groundwater condition.

Now in case if you have the actual water pressure data that is available so that should be stated and it should be expressed in terms of ratio of seepage water pressure to major principal stress

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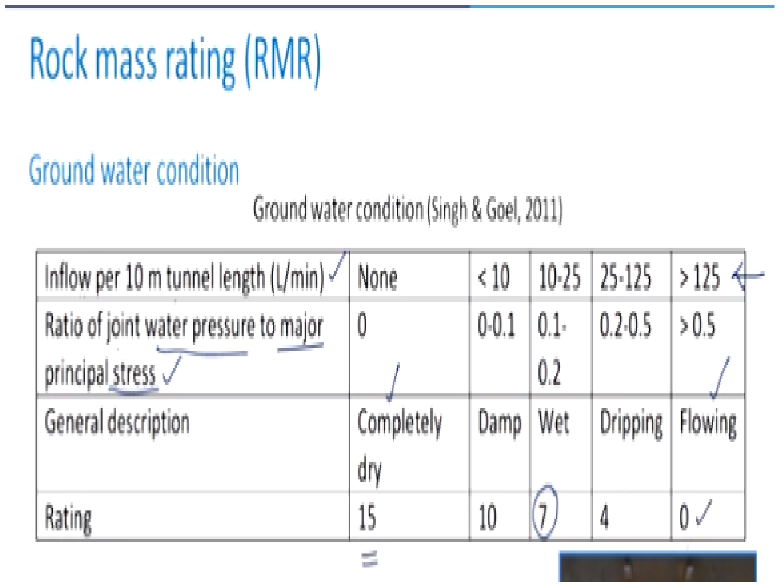

Inflow per 10 m tunnel length (L/min)	None	< 10	10-25	25-125	> 125
Ratio of joint water pressure to major principal stress	0	0-0.1	0.1-0.2	0.2-0.5	> 0.5
General description	Completely dry	Damp	Wet	Dripping	Flowing
Rating	15	10	7	4	0

Now take a look at this table and see how we can assign the rating in case if you have the information about inflow per 10-meter tunnel length that is in litter per minute. Then you have to use this row and there you have this ratio of joint water pressure to major principal stress. So, this is there when you have the information about the water pressure but in case if these are not available if you have only the general description with you.

Let us say, that the groundwater condition falls under the category of wet then what is the rating that you will assign it will be 7. So, accordingly it will vary from completely dry to flowing condition and corresponding rating will vary from 15 and it will reduce to 0 here.

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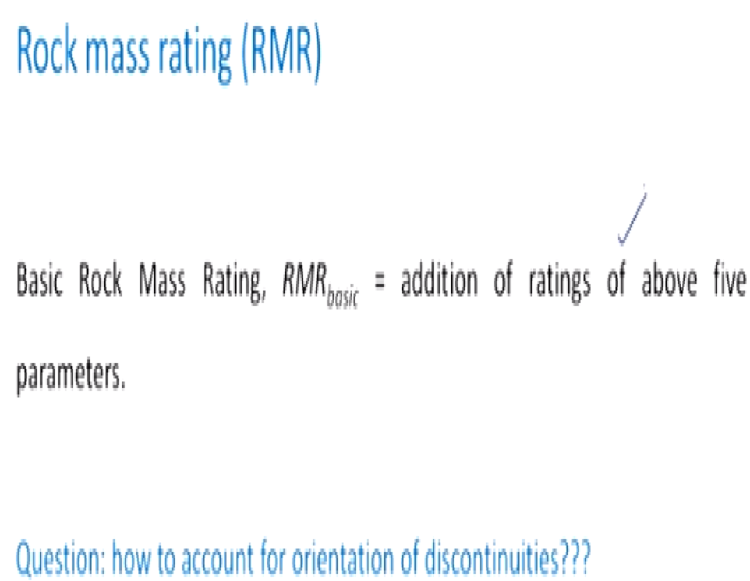

So, we have got the rating for all these 5 parameters so now what we do is? We are in a position to find out the basic rock mass rating that is the addition of ratings of the above 5 parameters which we discussed. Now the question comes that how should we account for the orientation of discontinuities let us take a look.

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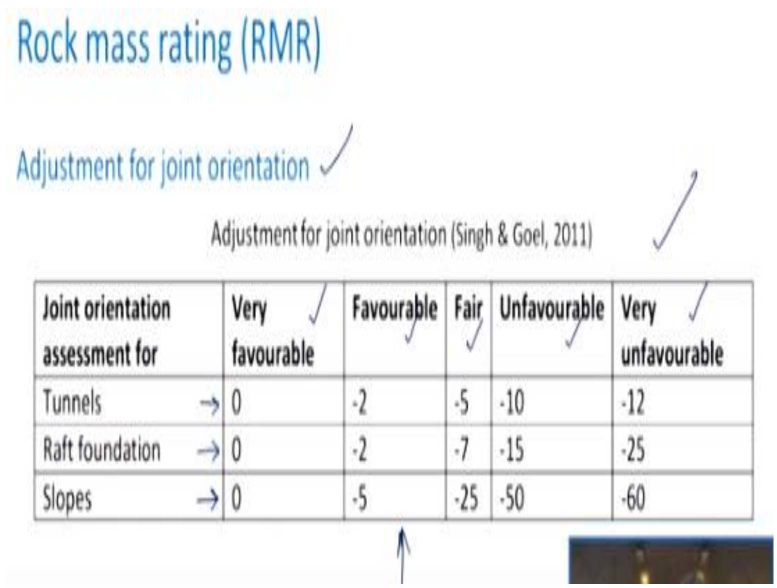

Joint orientation assessment for	Very favourable	Favourable	Fair	Unfavourable	Very unfavourable
Tunnels	0	-2	-5	-10	-12
Raft foundation	0	-2	-7	-15	-25
Slopes	0	-5	-25	-50	-60

So here is the table that gives you the idea about the adjustment for joint orientation. So, you see for different type of structures different row is given. For example, for the tunnels it is this row that is to be considered for rough foundations it is this row and for slopes related problems it is the last row of this table is to be used. Now based upon what is the orientation of the joint with reference to the orientation of the structure?

You have various categories, whether it is very favorable to favorable, fair, unfavorable and very unfavorable. So, based upon that you pick the rating from this table then what should be the next step? We already have the RMR basic with us now, what we do is we pick the rating for the adjustment of joint orientation from this table and we apply this adjustment to RMR basic to get the final value of rock mass rating.

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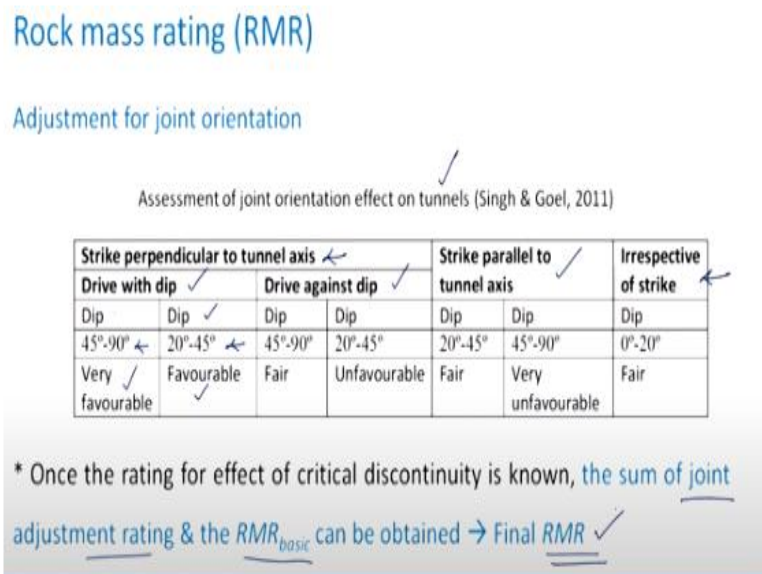

Strike perpendicular to tunnel axis				Strike parallel to tunnel axis		Irrespective of strike
Drive with dip		Drive against dip				
Dip	Dip	Dip	Dip	Dip	Dip	Dip
45°-90°	20°-45°	45°-90°	20°-45°	20°-45°	45°-90°	0°-20°
Very favourable	Favourable	Fair	Unfavourable	Fair	Very unfavourable	Fair

Another question before we do this or before, we get the final RMR value that, how do we decide whether the joint is favorably oriented or unfavorably, oriented. So here is some guideline that is given in this table with reference to the tunnels. So, various aspects are given whether the strike is perpendicular to tunnel axis. So, when we say strike that means I am specifically talking about the strike of that particular discontinuity.

In case, if the strike is parallel to the tunnel axis or if you have the joint that is irrespective of its strike so there also, we can get some idea. So, the drive with dip or drive against dip in case if it is dry with dip if the dip is in between 45 to 90 degrees then it is very favorable if the dip is in between 20 to 45 degree it is favorable. So, likewise, you have various condition based upon the orientation of the joint with respect to the orientation of the tunnel axis.

So, accordingly, you find out what is the condition of the joint orientation whether it is very favorable or it is fair or it is very unfavorable accordingly. We can use this table to assign the rating for the adjustment for joint orientation. Now since we have got this the sum of the joint adjustment rating and the RMR basic that we have already obtained that is going to give us the final value of RMR for that particular structural unit of the rock mass.

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Rock mass rating (RMR)

Design parameters and engineering properties of rock mass (Singh & Goel, 2011)

S. No.	Parameter/properties of rock mass	RMR (rock class) 100-81 (I)	80-61 (II)	60-41 (III)	40-21 (IV)	< 20 (V)
1	Classification of rock mass	Very good	Good	Fair	Poor	Very poor
2	Average stand up time	20 yrs for 15 m span	1 yr for 10 m span	1 week for 5 m span	10 hrs for 2.5 m span	30 mins for 1 m span
3	Cohesion of rock mass (MPa)	> 0.4	0.3-0.4	0.2-0.3	0.1-0.2	< 0.1
4	Angle of internal friction of rock mass	> 45°	35-45°	25-35°	15-25°	< 15°
5	Allowable bearing pressure (t/m^2)	600-440	440-280	280-135	135-45	45-30
6	Safe cut slope (°)	> 70°	65	55	45	< 40

The, question is what do we do after that? So, once we have got the RMR value (refer time: 25:07) for the rock mass what we can do is we can have various information that would be useful in the, some design and the analysis of various projects. So let us say that the RMR works out to be say 90 so it falls under the first category here. So, focus on this column the classification of the rock mass as per the RMR system will be very good.

And, it will give you the idea about the average stand-up time which will be 20 years for 15-meter span of the tunnel. It will also give you the idea that what would be the range for the cohesion and angle of internal friction of the rock mass. In case if you have foundation related problem then the allowable bearing pressure will be to the tune of 600 to 450 ton per meter square. And safe cut slope in this case is going to be greater than 70 degrees.

So, similarly, once you obtain the value of RMR you can choose that what is the classification of the rock mass, and then maybe you can choose the representative parameters. Such as average stand-up time, shear strength, parameters allowable bearing pressure, and safe cut slope with reference to that value of RMR. So, this is how we classify the rock mass using rock mass rating system.

And once we know the value of RMR we can have various applications as shown in this particular table to be applied to the rock mass under various projects. Be it for tunnel foundation-related problem or slope-related problem. So, thank you very much so in the next class we will discuss about the other classification system that is Q-system and GSI, thank you.