Rock Engineering
Prof. Priti Maheshwari
Department of Civil Engineering
Indian Institute of Technology - Roorkee

Module - 5
Lecture - 22
Classification of Rock Mass: Rock Mass Rating (RMR) - 2

Hello everyone. In the previous class, we discussed about the classification system that is rock mass rating. We saw that there are six parameters, which are to be considered while determining this rock mass rating. We saw that using the rating assigned to the 5 parameters and summing them up, we could get the value of RMR basic. And I left you with a question that how to account for the orientation of discontinuities.

So, let us try to find out the answer to this question in this class, along with the determination of rock mass rating and how the rock mass can be classified on the basis of this RMR. Then, we will have some discussion on the application of rock mass rating.

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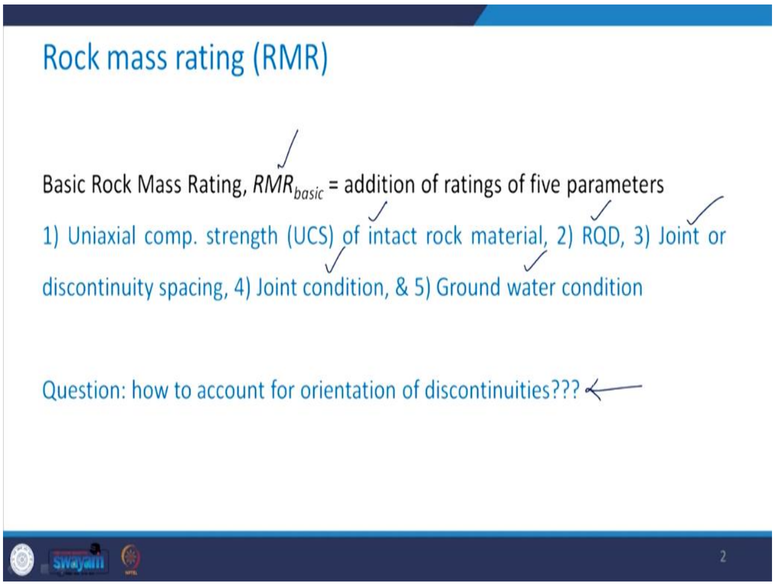

We saw that there were 5 parameters; UCS of the intact rock material, RQD, joint spacing, joint condition and groundwater condition. And we saw that how based upon the value of; or each of these parameters, how the ratings can be assigned to each one of these and those rating and their addition is going to give us the RMR basic. We need to find the answer to this question.

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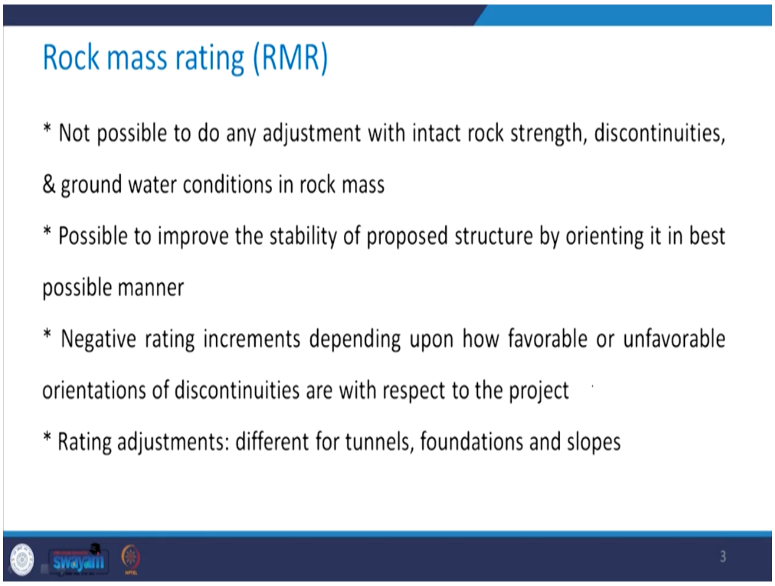

Take a look here. This is really very interesting. It is not possible to do any kind of adjustment with intact rock strength, discontinuity and the groundwater condition in a rock mass. Whatever is the intact rock strength that is going to be there? We really cannot alter that. Whatever are the characteristics of the discontinuities which are there in the field, they are also going to be there.

We cannot alter them. Similarly, whatever are the groundwater conditions in the rock mass, in the field, they are also not going to change. What about the orientation of the discontinuities? Can we change that? No, we cannot change that. But what we can change is the orientation of the proposed structure relative to the orientation of the discontinuities. Little bit of change, if the space is available; and it will be possible to improve the stability of the proposed structure in the best possible manner.

For example, let us say that you have a site and you have to decide the axis of the tunnel. You take a direction as far as axis of the tunnel is concerned. And then you carry out these analysis like whether the; in which direction the discontinuities are dipping; what exactly is their dip direction, etc. And then you try to take the relative orientation of these 2 things, which are discontinuities and the tunnel axis.

Accordingly, you can decide whether the discontinuities are favourable or unfavourable towards the construction of the tunnel. If they are unfavourable, then we can just change the orientation of the tunnel by few angles and then try to see whether we can get some better situation or not. What I mean to say by putting this point in front of you is: It is really not possible to do any adjustment with intact rock strength, discontinuities and groundwater conditions, but it is possible to improve the stability of the proposed structure by orienting it in the best possible manner relative to the orientation of discontinuities.

Negative rating increments depending upon how favourable or unfavourable orientations of discontinuities are with respect to the project. They are being assigned as far as the adjustment for the orientation of the discontinuities are concerned towards the calculation of final value of rock mass rating. These rating adjustments, they are different for tunnels, foundations and slopes. Here, these different adjustment for different situations, different structures, they are given.

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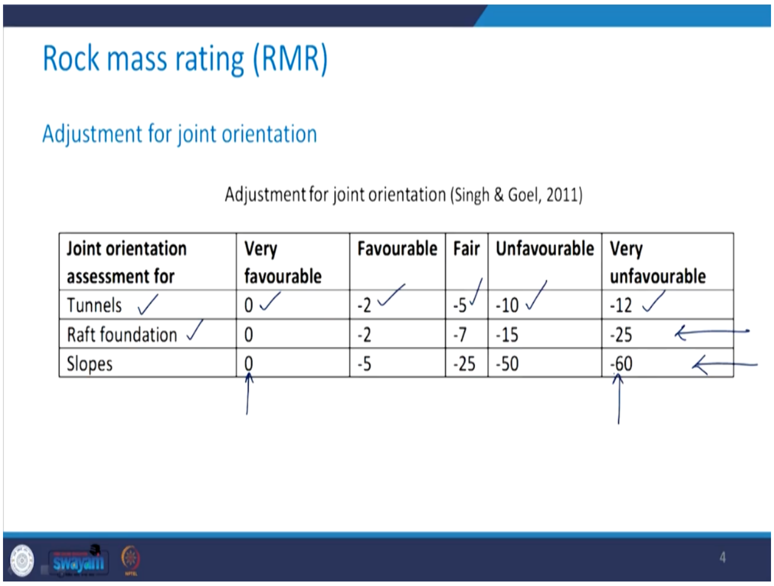

Joint orientation assessment for	Very favourable	Favourable	Fair	Unfavourable	Very unfavourable
Tunnels	0	-2	-5	-10	-12
Raft foundation	0	-2	-7	-15	-25
Slopes	0	-5	-25	-50	-60

Like for example, you take the case of the tunnel. In case if it is very favourable, then you do not need to apply any correction for the joint orientation. If it is favourable, then whatever is the RMR basic that you have obtained -2 is going to give you the final RMR value. Likewise, you can see that for fair it is -5; for unfavourable condition, it is -10; and for very unfavourable, it is -12.

In case if you have the raft foundation, then in that case, this row is giving you the rating for the joint adjustment. Then, for the slope, it is the last row. So, you can see that, for very favourable condition, it is 0 and for very unfavourable condition, this is -60. So, this table gives us the idea about the joint orientation adjustment for 3 different cases: tunnels, raft foundation and slopes.

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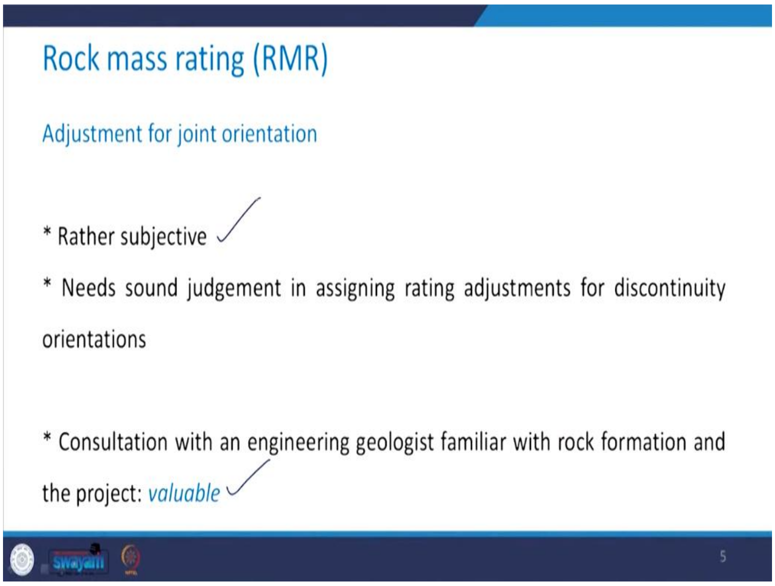

So, these are rather subjective. How? We will be able to decide whether it is unfavourable or not that unfavourable or favourable or it is fair; that is very, very subjective. So, therefore, this joint orientation adjustment, it needs sound judgment in assigning the rating for the discontinuity orientation. And this should be done in consultation with an engineering geologist who is familiar with the rock formation and the project.

So, his advice would be really valuable in such cases, because these ratings are quite subjective in nature. For example, let us say that I take an example of the tunnel. You can see that there are 3 pictures here.

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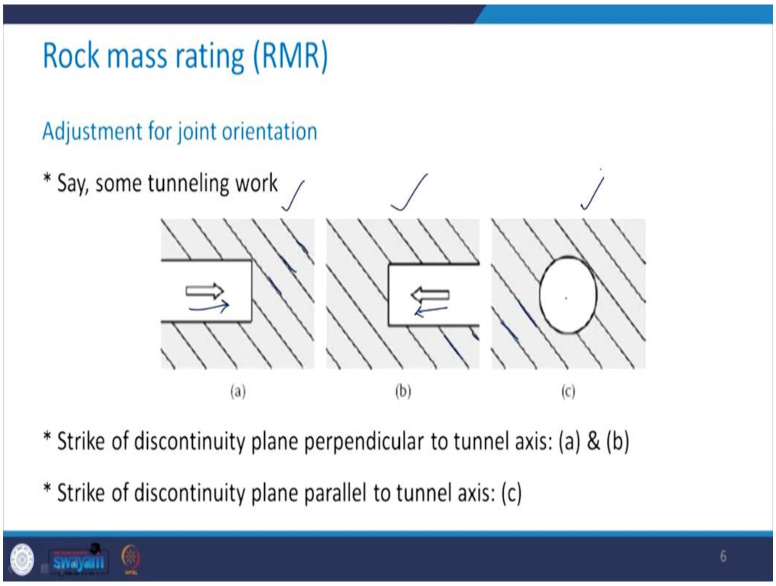

In all these 3 cases, the joints are dipping in this direction; in all the 3 cases. In first case, this is the direction of the tunnel drive. In the second case, it is in the opposite direction. And in the third case, it is perpendicular to the plane of this screen. So, what does that mean that this A and B; in these 2 cases, strike of discontinuity plane is perpendicular to the tunnel axis. However, in case C, the strike of discontinuity plane is parallel to the tunnel axis. How to decide whether which one is favourable and which one is not?

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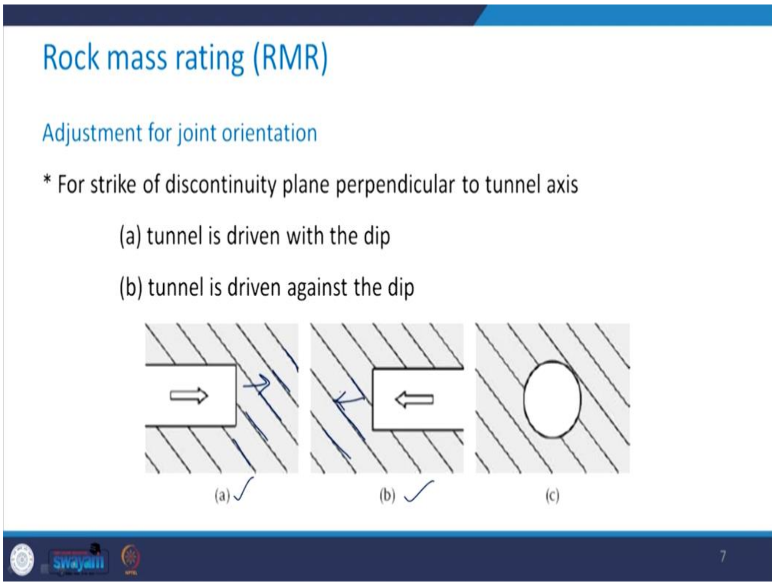

So, for a strike of discontinuity plane which is perpendicular to the tunnel axis; that means, these 2 cases. The first situation can be that tunnel is driven with the dip. So, you see that all the discontinuities, they are dipping in this direction. These joint sets are dipping in this direction. And tunnel is also being driven in this direction. So, tunnel is driven with the dip. However, in case B it is different.

It is other way round, that tunnel is driven against the dip. That is, it is all the joints are dipping in this direction and the tunnel is being driven in this direction which is against the dip.

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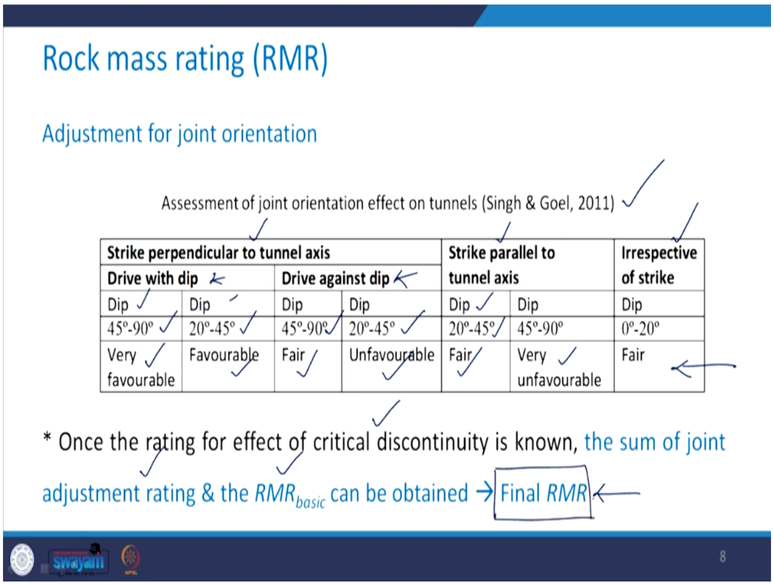

Strike perpendicular to tunnel axis				Strike parallel to tunnel axis		Irrespective of strike
Drive with dip		Drive against dip				
Dip 45°-90°	Dip 20°-45°	Dip 45°-90°	Dip 20°-45°	Dip 20°-45°	Dip 45°-90°	Dip 0°-20°
Very favourable	Favourable	Fair	Unfavourable	Fair	Very unfavourable	Fair

So, based upon this; take a look at this table that strike, when it is perpendicular to tunnel access; strike, when it is parallel to tunnel access; and this is irrespective of strike. So, drive with dip and drive against the dip. You have dip values. So, if it is 45 to 90 degree, it will be said that, okay, this is very favourable. If it is 20 to 45 degree, it is favourable. If the tunnel is driven against the dip and if the dip is 45 to 90 degree, it is fair.

And for 20 to 45 degree of dip, it is unfavourable. Similarly, for the C case where the strike was parallel to the tunnel axis; if you have dip between 20 to 45 degree, it is fair. Otherwise, it is very unfavourable. So, this table gives us the idea that how to decide whether the orientation of the joints, they are favourable, very favourable, fair or unfavourable for the driving of the tunnel.

Similarly, you can decide for slopes or the foundations on the weak rocks. So, first you make the use of this table and decide which condition this is belonging to. And then refer to the previous table to the corresponding value of the adjustment for joint orientation. So, once the rating for the effect of critical discontinuity is known, the sum of joint adjustment rating and RMR basic gives you the final value of RMR.

So, as far as RMR basic is concerned, there is no problem. We just have to add the rating corresponding to each of those 5 parameters. For the adjustment of the joint orientation, first you need to find out whether the joints are favourably oriented or unfavourably oriented with respect to that structure. And how this is done? I just explained that to you. Once you know the adjustment for the joint orientation, then you just add that adjustment rating with the RMR basic. And you will be able to get the final value of RMR.

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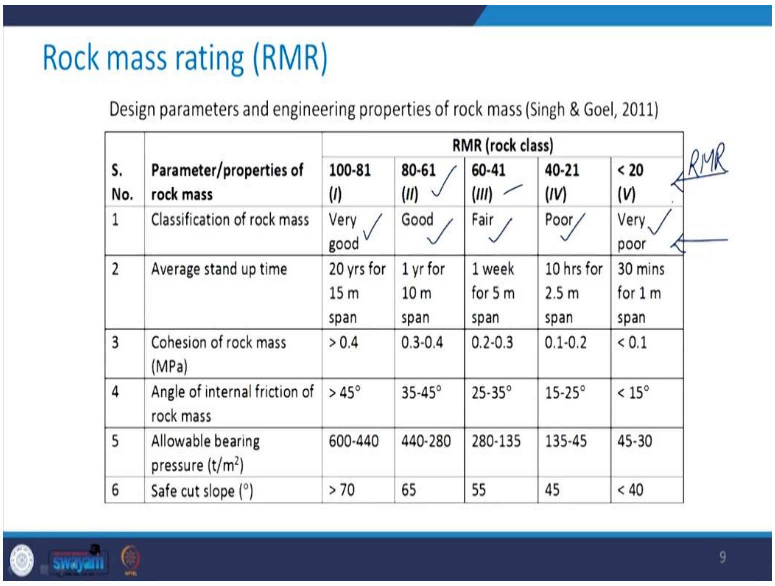

S. No.	Parameter/properties of rock mass	RMR (rock class)				
		100-81 (I)	80-61 (II)	60-41 (III)	40-21 (IV)	< 20 (V)
1	Classification of rock mass	Very good	Good	Fair	Poor	Very poor
2	Average stand up time	20 yrs for 15 m span	1 yr for 10 m span	1 week for 5 m span	10 hrs for 2.5 m span	30 mins for 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/m²)	600-440	440-280	280-135	135-45	45-30
6	Safe cut slope (°)	> 70	65	55	45	< 40

Have a look at this column. The first one is giving you the value of RMR and the second one gives you the corresponding value of the classification of rock mass. So, if the value of RMR works out to be in between 81 to 100, this falls under the category of very good. So, we can say that the rock mass is of very good quality. If it is 80 to 61, it is good quality. Rock mass between 41 to 60, fair quality; 21 to 40, it is poor quality. And if the rock mass rating works out to be less than 20, then the rock mass quality is said to be very poor.

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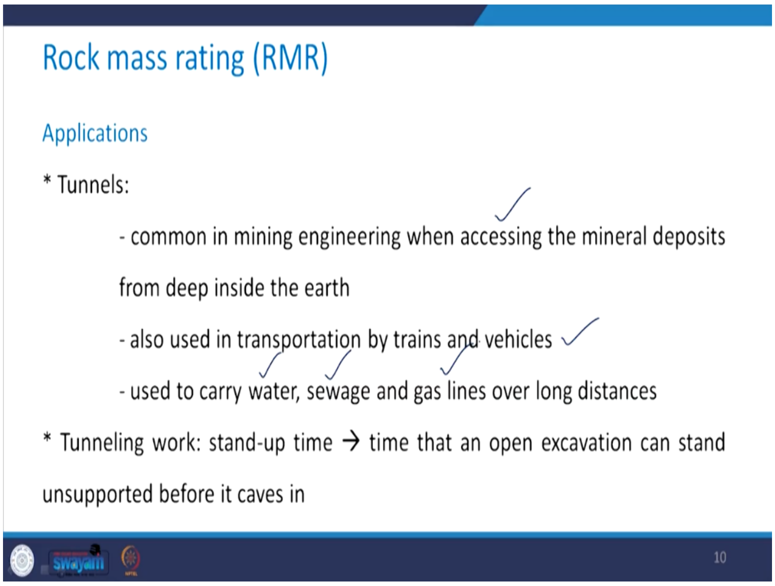

Coming to some of the application areas for this rock mass rating; So, first one we take it as the tunnels. You all know that construction of tunnels, they are very common in mining engineering, where we need to access the mineral deposit from deep inside the earth. So, what we need to do is, we need to have the small tunnel to go to that deep inside the earth, in order to have the access to the mineral deposits.

Then, these are also used in the transportation, maybe by trains or vehicles. Some of you must have experienced the travel through the tunnels at some point of time or other. These tunnels are also used to carry water, sewerage and gas lines over long distances. And therefore, these are one of the most important structures on the rocks. As far as tunnelling work is concerned, the stand-up time is one of the most important aspects with respect to this.

How should we define this stand-up time? It is the time that an open excavation can stand unsupported before it caves in. So, once you have made the excavation, one need to go and provide the support system. That support system can be in the form of lining, shotcrete or anything, rock bolts. So, the stand-up time defines the time that the excavation can withstand unsupported without caving in.

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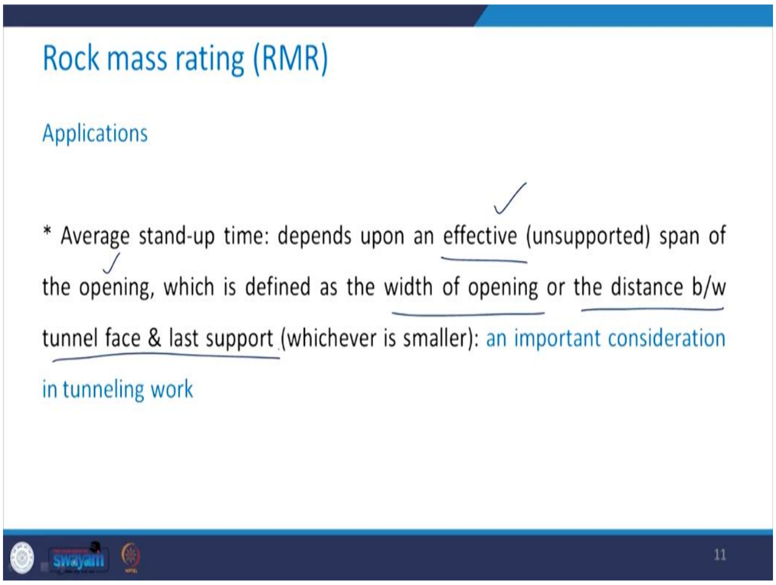

So, average stand-up time: It depends upon the effective span of the opening. That effective span is defined as the width of opening or the distance between the tunnel face and the last support, whichever is small. And this is of an important consideration in tunnelling work.

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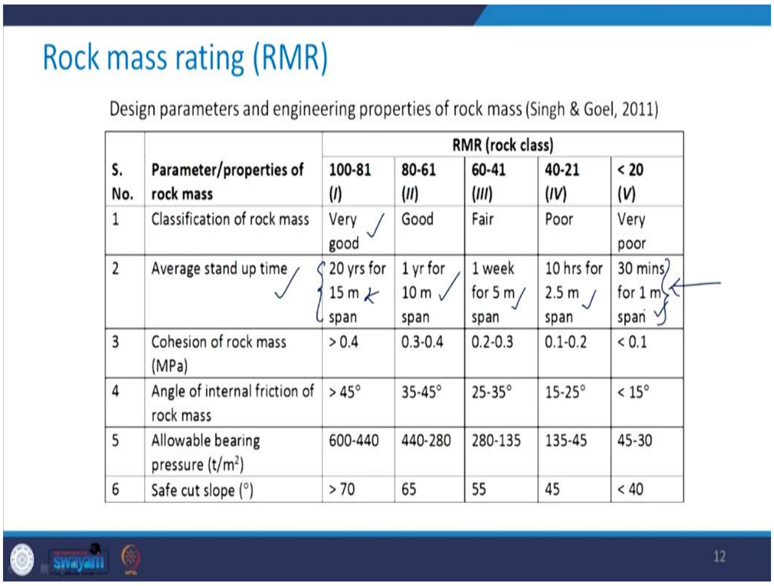

Rock mass rating (RMR)

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

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6	Safe cut slope (°)	> 70	65	55	45	< 40

Take a look at this table once again and focus on this row. This gives us the idea about the average stand-up time. So, in case if you have very good quality of rock mass, the average stand-up time is 20 years for 15m of span. That means, 15m of span can stand-up to 20 years without caving in. Likewise, there is other for good rock mass, fair rock mass, poor rock mass and very poor rock mass.

So, you see that, as the quality of the rock mass deteriorates, the stand-up time reduces. See, from 20 years for 15m span to 30min for 1m span. Let us have some more discussion on the stand-up time.

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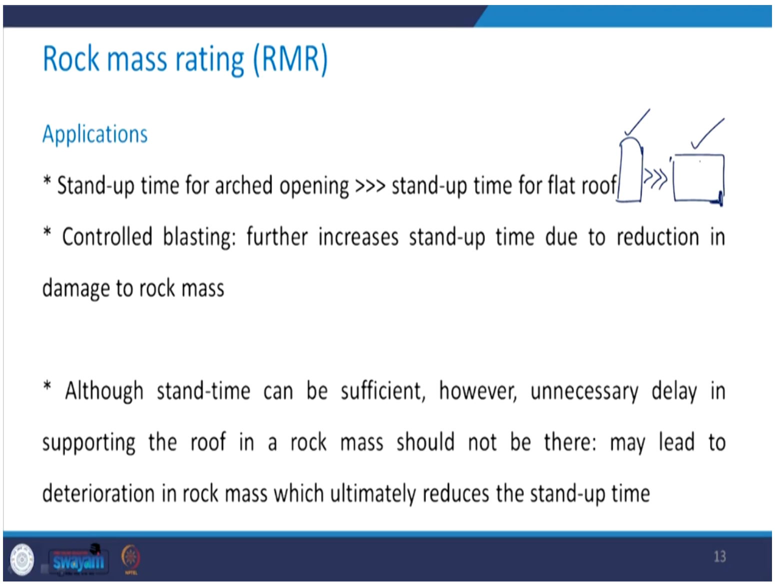

So, the stand-up time for arched opening is much, much larger than the stand-up time for the flat roof. So, what I mean to say is, you can have this kind of tunnel cross section or you can have this kind of tunnel cross section. Where in this case you have the arched roof and in this case you have the flat roof. So, the stand-up time is going to be larger for this case as compared to that case.

Now in case for the excavation purpose; if you are going for the controlled blasting, so that further enhances the stand-up time. Because, when we go for the control blasting, there is going to be the reduction in the damage to the rock mass. And therefore, the stand-up time increases. You have seen that a stand-up time can be as large as 20 years for 15m span of the panel, in case of a very good quality rock mass.

Although you have sufficient stand-up time, but unnecessarily we should not wait till the end of that time in order to provide the support system in the rock mass. Because, what happens; although the rock mass can withstand up to that much of the stand-up time; but what happens; wherever there is a free surface, the stress release is there. And there will always be the deterioration in the rock mass, which will ultimately reduce the stand-up time. So, even though you have sufficient stand-up time, unnecessarily you should not delay the process of the installation of the support system in that rock mass.

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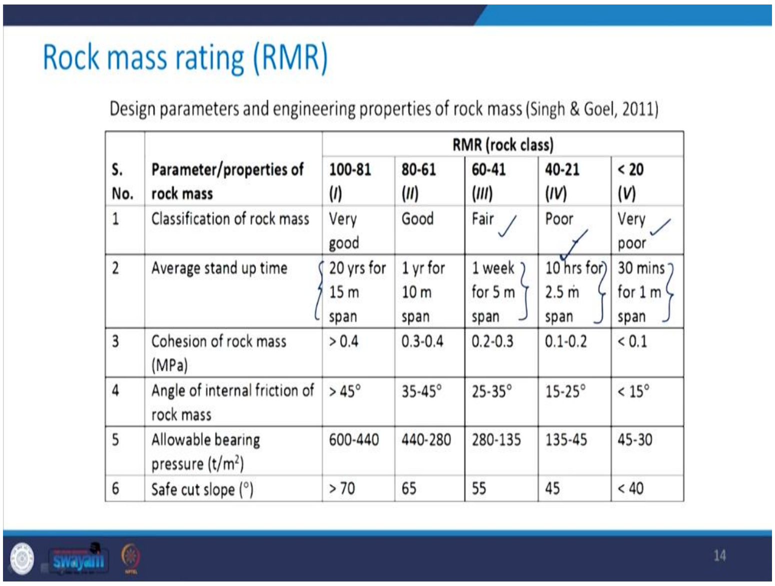
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5	Allowable bearing pressure (t/m^2)	600-440	440-280	280-135	135-45	45-30
6	Safe cut slope (°)	> 70	65	55	45	< 40

As I explained that, here it is, you see that 20 years for 15m span. So, it should not that we should wait for 5 years to provide the support system because the stand-up time is this large. No, as soon as we excavate and it is convenient, we should; convenient in the sense convenient from the point of view of the construction activity; immediately we should provide the necessary support system.

Obviously, in case you have very good rock mass, you may have very nominal requirement for the support system. This installation of the support system becomes quite crucial in case if you have fair, poor or very poor quality of rock mass. Because you can see that here, it is 1 week for 5m span; 10hr for 2.5m span; and here it is only 30min for 1m span.

So, although here you have 10hrs for this 2.5m span, but you should not wait till 9hrs and then only go for the installation of the support system. Because, in those 9hrs, the rock mass quality after excavation will deteriorate. And ultimately, the effective average stand-up time may not be this 10hrs for 2.5m span. So, we have to be careful about this.

The second application is that, if we have the value of RMR, we can determine cohesion and angle of internal friction for that rock mass, where this assumption is inbuilt that the rock mass is following the Mohr-coulomb failure criteria.

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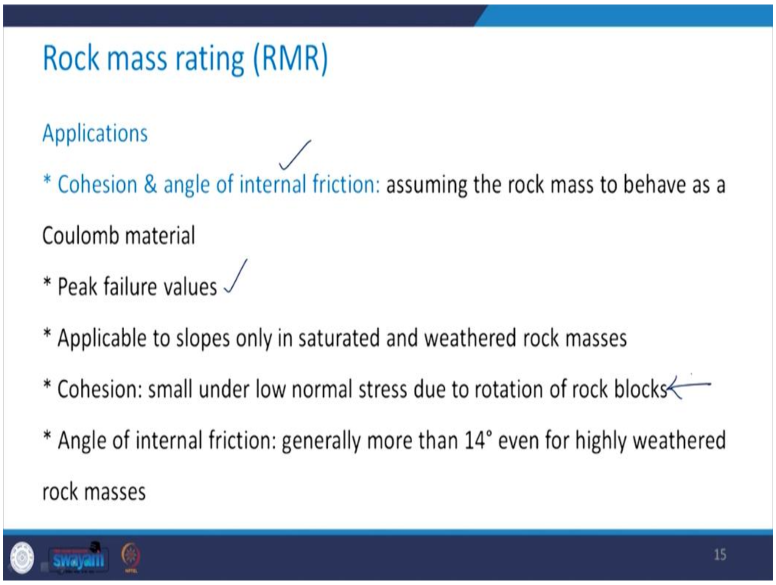

This RMR will give us the peak failure values. This is applicable to slopes only in the saturated and weathered rock masses. Cohesion is going to be small under low normal stress due to the rotation of the rock blocks. And the angle of internal friction; it is generally more than 14º even for highly weathered rock masses.

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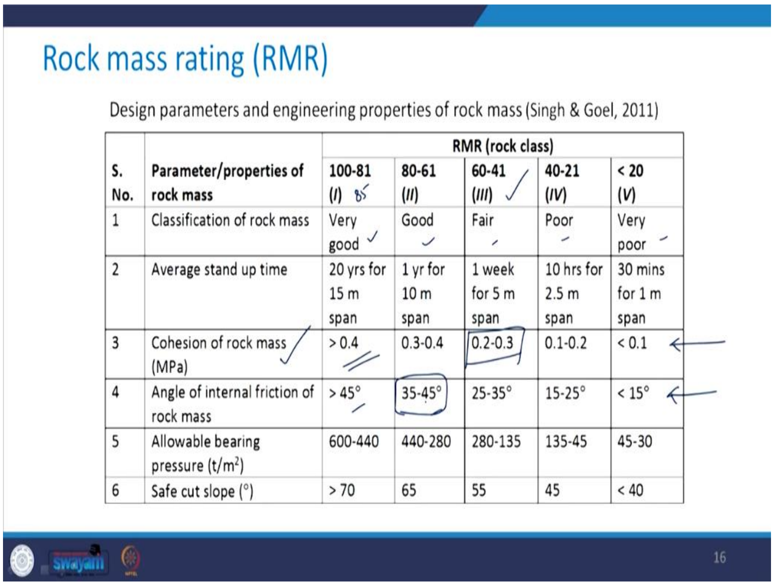

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6	Safe cut slope (°)	> 70	65	55	45	< 40

Once again I refer to this table. Look here on this row which gives you the cohesion of the rock mass in MPa. So, say you have the RMR of say 85. So, 85 would lie in this range. So, its cohesion is going to be greater than 0.4MPa. Say it is 55. So, 55 will lie in this range. And the cohesion of the rock mass; you can get the idea that it is in between 0.2 to 0.3. So, this way, rock mass rating is helpful in getting some idea about the cohesion of the rock mass.

Coming to the next shear strength parameter, which is the angle of internal friction for the rock mass. Take a look at this row where you have these values depending upon whether it is very good, good, fair, poor or very poor kind of a rock mass. You have the range of the angle of internal frictions. For example, for good quality of rock mass, the range is between 35º to 45º.

You need to keep in mind that even for the highly weathered rock; the angle of internal friction will be more than 14 to 15º. So, it will not go further below. That like, it cannot be 10º or 5º. So, please remember that.

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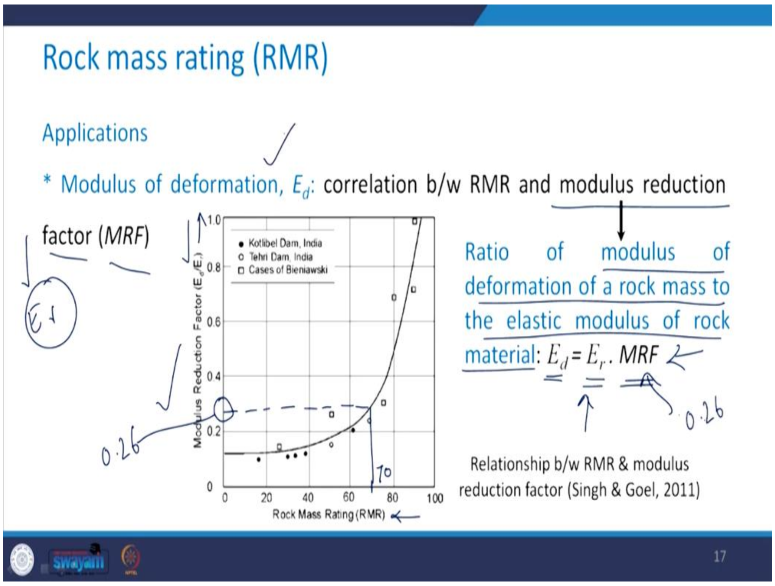

The next application is the determination of modulus of deformation. I already defined this for you that how the modulus of deformation is different than the elastic modulus. So, the correlation between RMR and the modulus reduction factor which is MRF is given in this figure. This factor, modulus reduction factor or MRF is defined as the ratio of modulus of deformation of the rock mass to the elastic modulus of the rock material.

When I say elastic modulus of the rock material means I am talking about the intact rock. So, you can see here that the deformation modular therefore will be: elastic modulus of the rock material multiplied by this factor which is MRF, modulus reduction factor. Take a look at this figure, which gives you the relationship between RMR and MRF. On the x axis, it is the RMR which has been plotted.

And on y axis, you have this ratio, E_d upon E_r. Now, say the value of RMR works out to be say 70. So, I take here the value 70. And I draw a line here; vertical line up to this plot. And then, I take this horizontal line from this point. And I can read this value. Say this is 0.26 in this case. So, corresponding to RMR of 70, we have this MRF to be equal to 0.26. Now, say this E_r value will be known to me; I can carry out the test in the lab; like let us say UCS test.

And from there, I can find out the elastic modulus for the rock material. So, once this is known to me; from the RMR, I can find out the ratio E_d upon E_r and just substitute that E_r and MRF in this expression. And you will be able to get the modulus of deformation.

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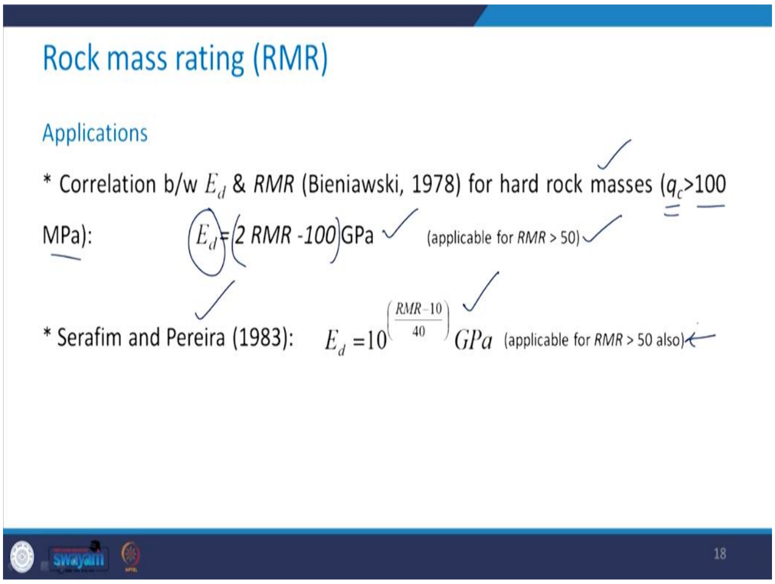

Some of the correlation between the modulus of deformation and RMR is also given. So, one which is there for hard rock masses; how should we identify the hard rock mass? That is, its UCS is going to be more than 100 MPa. So, for that, you will have this expression. That is,

$$E_d = (2RMR - 100)GPa \;;$$

that is gigapascal. And this is applicable for RMR more than 50. Because if RMR is less than 50, this E_d will become negative, which is physically not possible.

So, it has a condition associated with this that it is applicable for RMR greater than 50. The next one which is very important and quite often used is the expression which was given by Serafim and Pereira in 1983, where the deformation modulus is given as

$$E_d = 10^{\left(\frac{RMR-10}{40}\right)} GPa$$

And this is also in GPa. I mentioned to you earlier also that we need to be careful about the units, because all these expressions, they are empirical in nature. So, this expression is applicable for all the values of RMR.

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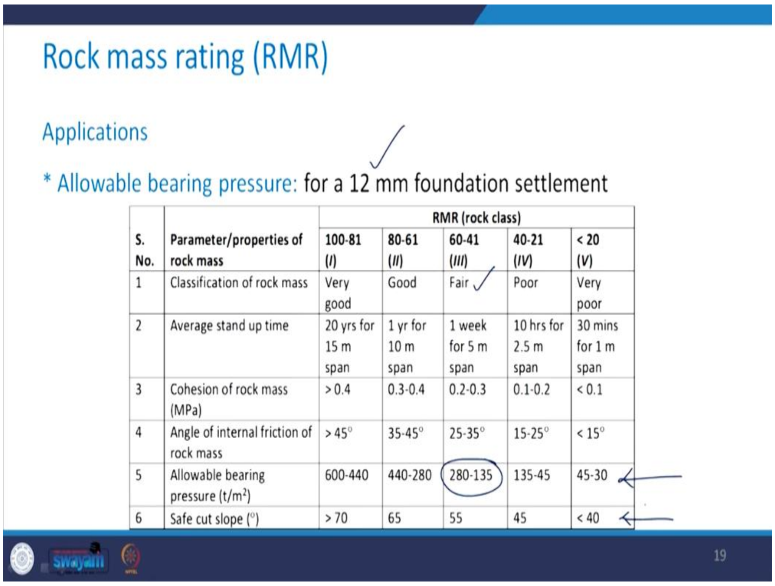

Coming to the next application, which is the allowable bearing pressure for the foundation. So, if we know the range or the value of the RMR, we can find out the allowable bearing pressure. And that is corresponding to 12mm of foundation settlement. So, say for example, if the rock mass is of fair quality, that is this column; so, the range of the allowable bearing pressure is going to be 135 to 280t/m^2.

So, one application area of RMR is this also, that you can get the allowable bearing pressure range for 12mm foundation settlement, corresponding to any value of RMR. Then, the next one is the safe cut slope. So, you can see that the angle has been given. So, depending upon the kind of rock mass quality that you have as far as RMR is concerned; accordingly, from this table, you can find out that what will be the safe cut slope in degrees.

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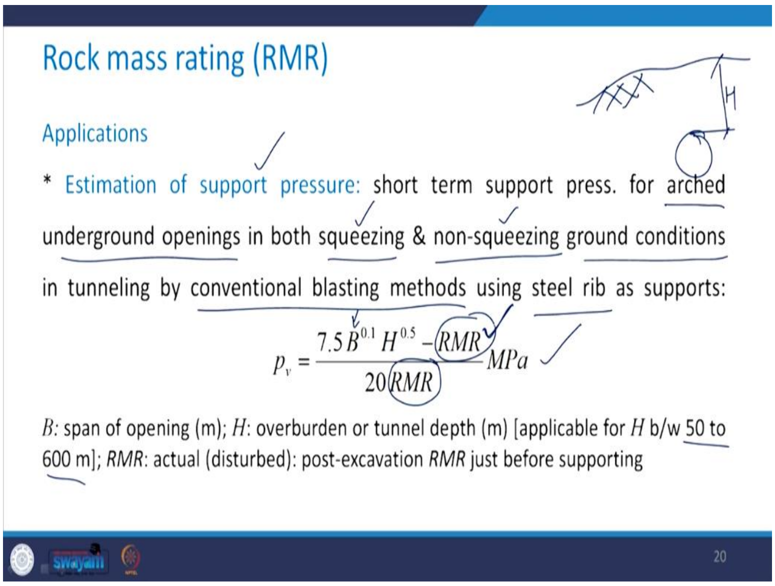

The next application includes the estimation of support pressure. So, short term support pressure for asked underground openings, both in squeezing and non-squeezing ground conditions: See right now, I am not going to explain you that what do we mean by squeezing and non-squeezing ground condition. When we go to the chapter on tunnelling, there we will discuss all these things in detail.

So, for the time being, you just think about this situation that RMR can also be used to estimate the support pressure for tunnels. So, if there is squeezing and non-squeezing ground condition in tunnelling and the conventional blasting methods are used; and steel rips are used as the support; then this expression gives you the idea about the estimation of the support pressure.

$$p_v = \frac{7.5B^{0.1}H^{0.5} - RMR}{20RMR} MPa$$

Here you can see that the RMR comes into picture; and B is the span of the opening in metre; and 'H' be the overburden or the tunnel depth. So, let us say this is the ground surface. And here you have, let us say the excavation. So, from this point to this point; this is going to be your H. This is called as the overburden. And this expression is applicable for H between 50 to 600m.

Take a note of it that RMR which you use here, it should be the actual one, that is the post excavation RMR just before the supporting. So, that value you should substitute here in this expression.

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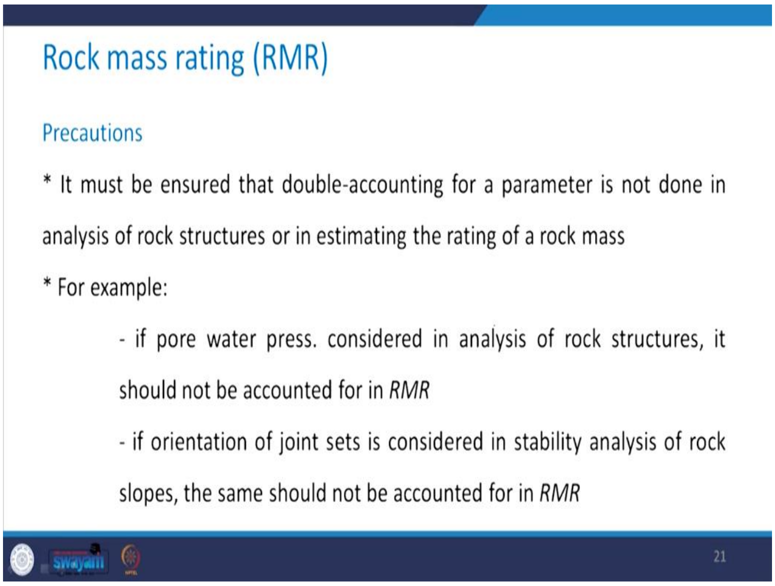

Some of the precaution that we should keep in mind when we use this classification system that is rock mass rating: We must ensure that double accounting for any parameter is not done in the analysis of rock structure or in the estimation of the rating of the rock mass. For example, if you have considered the pore water pressure in the analysis of rock structure, then this should not be accounted for in RMR.

That is, when you evaluate the value of RMR, then you should not bother about the groundwater condition. And if you have considered the orientation of the joint sets in the stability analysis of the rock slopes, then we do not need to bother about the adjustment for the joint orientation. So, any parameter should not be accounted for twice.

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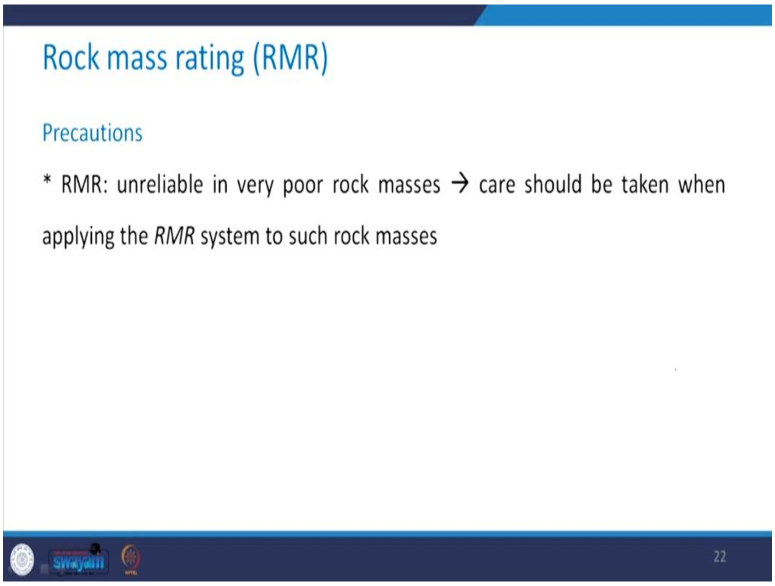

RMR is unreliable in very poor rock masses. And therefore, when we apply the RMR system to such rock masses which are very poor, we should be careful. We should use our engineering judgment when we apply this system to the poor rock masses, because the condition for which this system was developed was for the sedimentary rocks and for shallow tunnels.

And those rocks for which it was developed, they were not of very poor quality of the rock mass. So, we have to be careful when we use this RMR system to very poor rock masses. So, this finishes our discussion on the first classification system, which is the rock mass rating. So, you saw that there are 6 parameters which are to be considered to obtain this RMR. And on the basis of the value of RMR, you can classify the rock mass.

And then we saw various application areas of this classification system, RMR. So, in the next class, we will learn about another classification system which is rock mass quality or Q-system in detail. Thank you very much.