Under Space Technology
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Module No # 07
Lecture No # 33
Application of Rock Mass Classification System: Rock Mass Rating (RMR)

Hello everyone, in the previous class, we discussed the application of Terzaghi's rock load theory in the design of underground excavations. To continue with the discussion today, we will take up another rock mass classification system that is rock mass rating. We call it in short as RMR. And we will see that how the application of RMR happens in case of the underground excavations.

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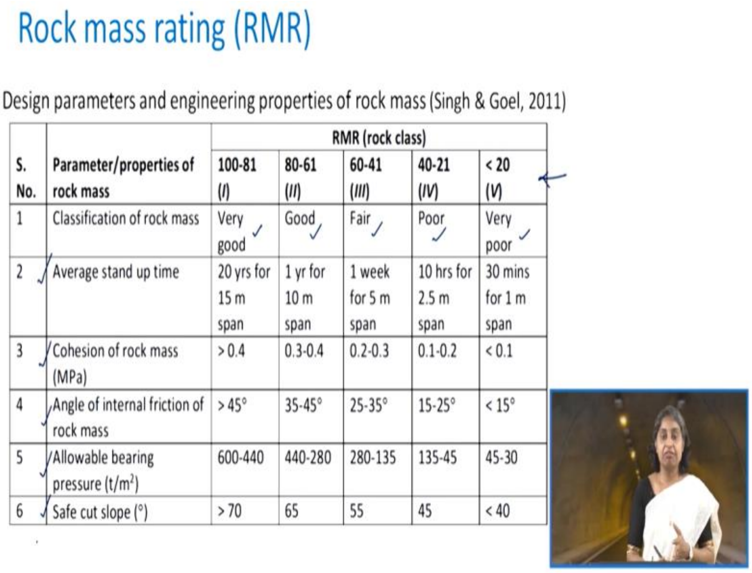

Rock mass rating (RMR)

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

So, you all know about this table this we have discussed in some of the earlier classes as well. So based upon the classification system RMR, we can classify the rocks as has been mentioned in this row accordingly, we can assign the rock mass to be very good, fair, poor, or very poor. So based upon this classification of rock mass, we can assign some engineering properties to the rock mass. Some of these include the average stand-up time, cohesion of rock mass, angle of internal friction of rock mass, allowable bearing pressure, and safe cut slope.

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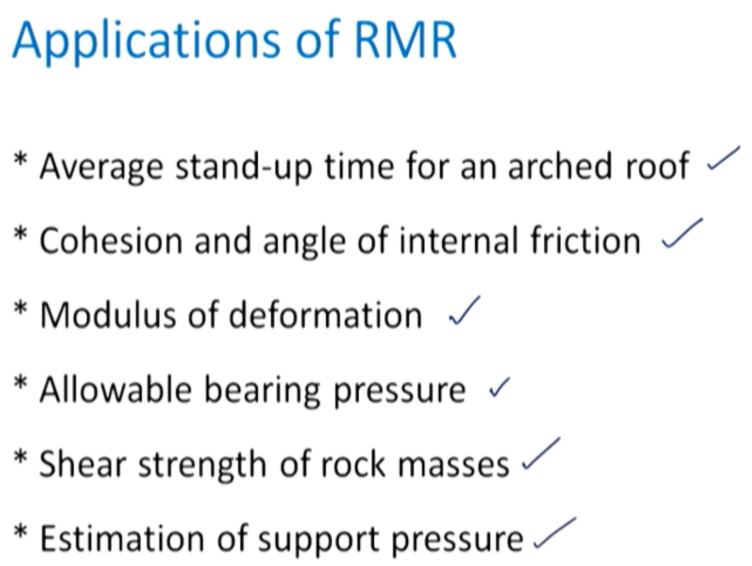

So, let us discuss this one by one. As I mentioned, the applications of RMR include average stand-up time for an arched roof. Then, cohesion and angle of internal friction, modulus of deformation, allowable bearing pressure in case, if you have the foundation to be resting on the rock mass. Then we need to design it using this information about the allowable bearing pressure, so there this application comes into picture. Then shear strength of rock masses and of course, the estimation of support pressure.

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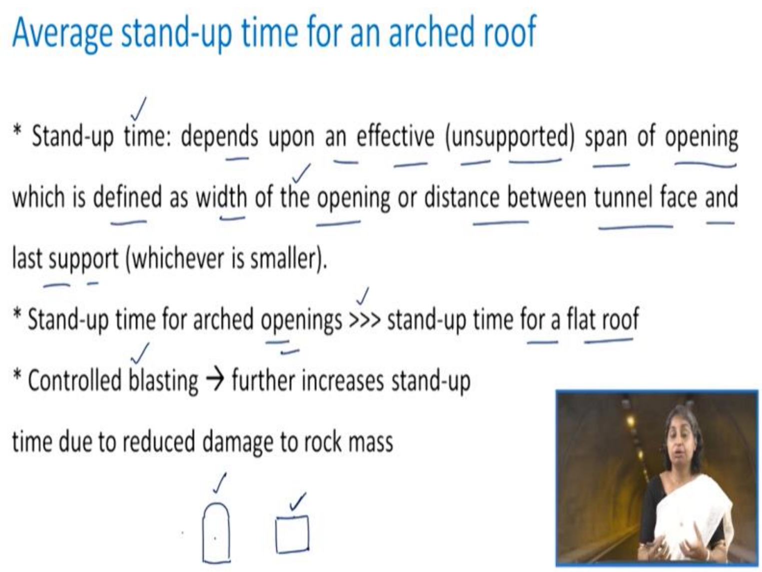

So first, let us take the average stand-up time for an arch group. So first, we understand that what do we mean by the stand-up time. Stand-up time is the time through which the tunnel can stand on its own, or the excavation can stand on its own without the provision of any support system. So, in case if the standard time is more, we have little more time for the installation of support system after the excavation.

But if the stand-up time is low, which will happen in case of the poor rock masses, then, in that case, the time for the installation of the support system is extremely low. And then we have to do proper planning in order to take care of such a situation. So, this is stand-up time. It basically depends upon an effective or unsupported span of opening, which is defined as the width of the opening or distance between the tunnel phase and the last support, whichever is smaller.

Whether the width of the opening is smaller or the distance between tunnel face and the last support is small. The stand-up time for the arched opening is much larger as compared to the stand-up time for the flat roof, so how it looks like? So, one excavation is like this it has the arched roof, and another excavation is like this, which has the flat roof. So, in this case, the stand-up time will be much larger as compared to the stand-up time in case of a flat roof.

If we go for the controlled blasting, this further enhances the stand-up time because with the control blasting, we can reduce the damage to the rock mass as compared to random plastic.

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Average stand-up time for an arched roof

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/m²)	600-440	440-280	280-135	135-45	45-30
6	Safe cut slope (°)	> 70	65	55	45	< 40

So, let us come back to this table again and focus only on serial number 2, which gives us the idea about the average stand-up time. So, in case if the raw class as per RMR is very good, then the average standard time is 20 years for 15 meters of span that means 15 meter of span of the excavation can stand on its own for 20 years.

So, this is so high because the rock mass rating for this type of rock is pretty high, varying in between 81 to 100, resulting in the classification of rock mass as very good. Coming to the next category, that is in case if you have the rock mass as good rock mass, then it is 1 year for 10 meter of span. In case if it is fair quality rock mass, it is one week for 5-meter span and so on. It keeps on reducing the stand-up time keeps on reducing along with the unsupported span length as well.

So, in case of the poor rock, it is minimum which 30 minutes for just 1 meter of span. Now one thing you need to keep in mind that although let us take, for example the fair type of rock mass so, although the average standard time is 1 week for 5-meter span. But we should not wait till the sixth day and then only go for the installation of support system on the seventh day. Because what happens is during those six days, the rock mass quality further deteriorates.

So, in case if you have the sufficient stand-up time, you should try to provide the support system as soon as possible. So, this was about the magnitude of average standard time for an arched roof.

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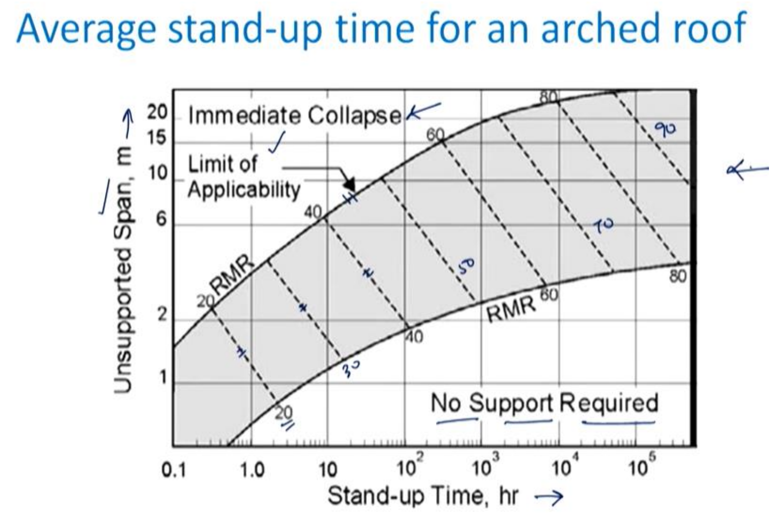

Stand-up time vs. unsupported span for various rock classes as per RMR
(Singh & Goel, 2011)

Now, various studies were conducted and based upon that the stand-up time versus unsupported span for various rock classes as per RMR was plotted. So, here on the x-axis, you have the stand-up time in hour; this is on the log scale, and on y-axis, you have the unsupported span of the excavation, this is also in the log scale. So, you can see that there is a limit of applicability which is shown by this upper portion of this shaded zone.

Below this, you have the zone where you do not need to provide any support system, and above this, you have the situation of immediate collapse. So, these dotted lines they represent the RMR, so this is for RMR 20, this is 30, 40, this is for 50, 60, 70, 80, and 90 and above. So based upon the RMR value, we can find out that what will be the stand-up time corresponding to any unsupported span of the opening. We can use this particular figure for the same.

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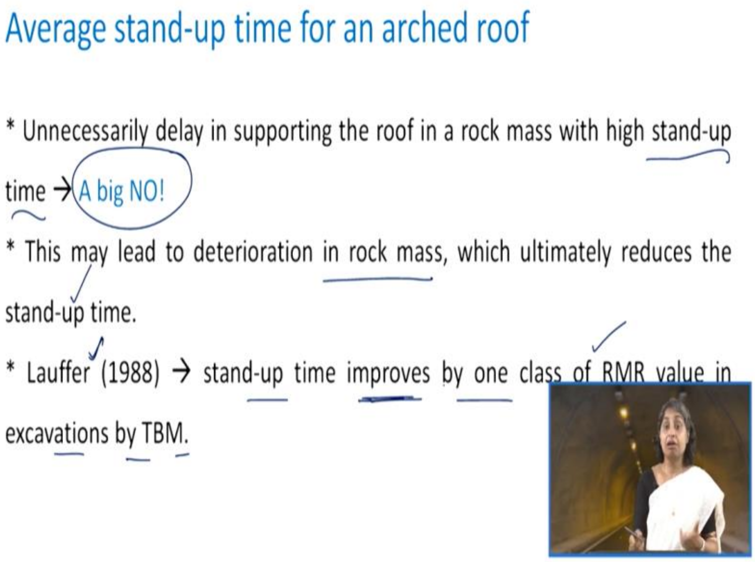

As, I mentioned that there should not be unnecessary delay in supporting the roof in a rock mass even though it has high stand-up time, so this is a big no. So, this may lead to the deterioration in rock mass which ultimately reduces the stand-up time. So, what this research worker mentioned that stand-up time improves by 1 class of RMR value in the excavation, which were made by tunnel boring machine.

So, we have seen that if we go for the controlled blasting as compared to the random blasting in case of the control blasting, the damage to the neighboring rock mass is low. But in case of the excavations which were done by tunnel boring machine, even the disturbance is even lower and hence the stand-up time improves by 1 class of RMR value.

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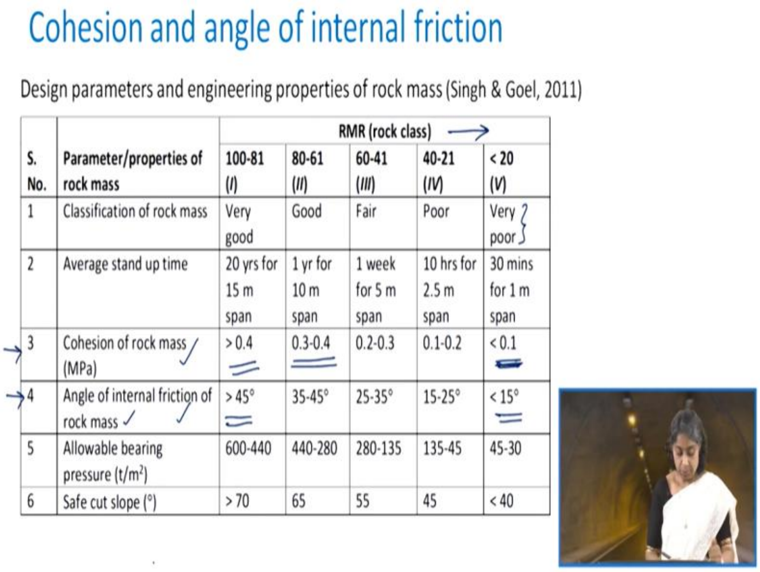

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6	Safe cut slope (°)	> 70	65	55	45	< 40

So, now coming to the next application, which is cohesion and angle of internal friction, so you need to focus now on serial number 3 and serial number 4. So, the first one focuses on the cohesion of the rock mass and the second one is angle of internal friction. So here, see how as the quality of the rock mass deteriorates in terms of RMR reduction in this direction. See how the cohesion of the rock mass also reduces.

So, for the very good quality rock mass, the cohesion is 0.4 MPa and more than that. And in case of the good quality, it is between 0.3 to 0.4 Mega Pascal. But in case if you have very poor-quality rock mass, the cohesion of the rock mass is as low as less than 0.1 Mega Pascal. Similar, is the situation with reference to angle of internal friction of the rock mass. See how this angle is varying from more than 45 degree to less than 15 degree as the rock mass classification changes from very good to very poor.

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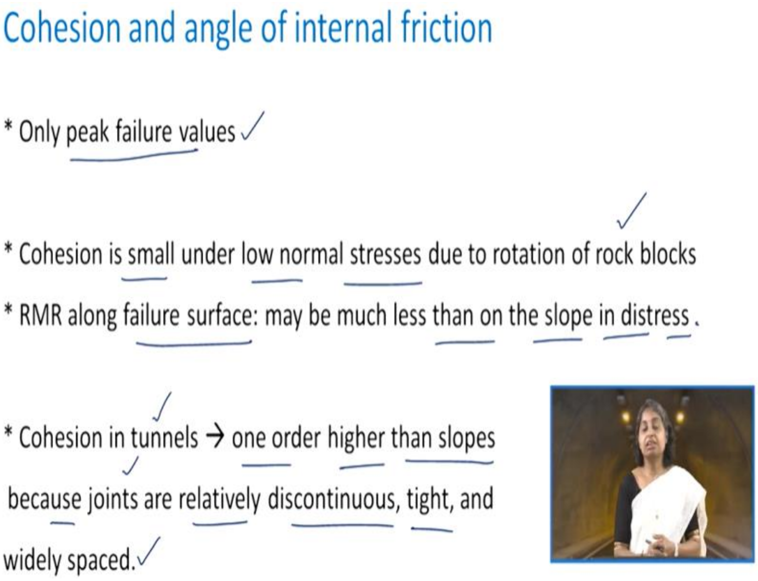

You need to keep in mind that here we are talking in terms of only peak failure values and not the residual one. You all know that when we go for the test shear strength test, we have one as the peak failure, another point as the residual one. So here, we are talking with reference to peak failure values. Cohesion is small under low normal stresses due to the rotation of rock blocks.

Now, RMR along the failure surface may be much less than on these slopes in distress as far as cohesion in tunnels are concerned. They can be one order higher than slopes because joints are relatively discontinuous tight, and widely spaced in case of the tunnels.

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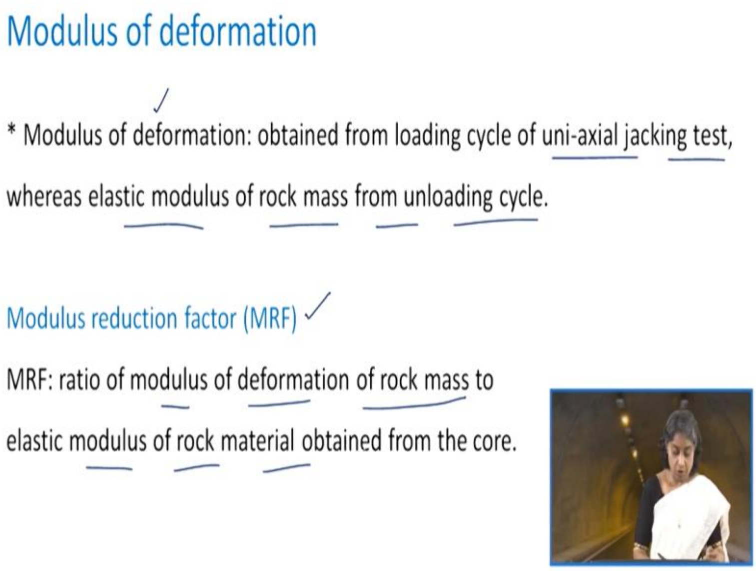

Coming to the next category that is modulus of deformation. So, we have discussed this earlier that how to determine the modulus of deformation. So, these are obtained from the loading cycle of uni-axial jacking test, whereas the elastic modulus is obtained from the unloading cycle. So basically, when we determine the modulus of deformation, it is the linear and the non-linear part of the loading cycle both is to be considered for the determination of modulus of deformation.

Then, we define another quantity which is modulus reduction factor. We call it in short as MRF. Which is the ratio of modulus of deformation of rock mass to the elastic modulus of rock material which is obtained from the core. When I say obtained from the core means that the test which is conducted on the intact rock specimen.

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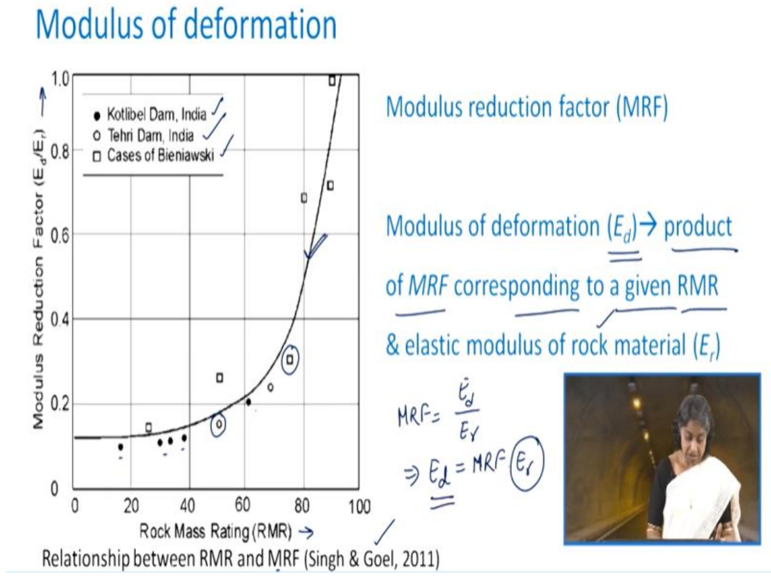

So, here is a relationship that was given by these research workers between RMR and MRF. RMR is rock mass rating which is plotted on x-axis, and MRF is modulus reduction factor. I just now defined it, and this is plotted on y-axis. So, from here, corresponding to any value of rock mass rating, we can determine that what is the modulus reduction factor. Once we know the modulus reduction factor, we can find out from this expression that is:

$$MRF = \frac{E_d}{E_r}$$

$$E_d = MRF \times E_r$$

So basically, this modulus of deformation E_d is a product of MRF corresponding to a given RMR value and the elastic modulus of rock material which is represented as E_r. Now, how this plot was developed? So various cases related to Indian conditions and abroad were plotted on the same space, that is MRF versus RMR, and these points which are shown here these represent the regions for the situation for Kotibel dam India.

Then, the circular one is Tehri dam India, and then the square one these represent the cases of Bieniawski. So basically, they try to derive a relationship between the modulus reduction factor and RMR in general. And, then they try to suggest that how we can determine the modulus of deformation using this RMR.

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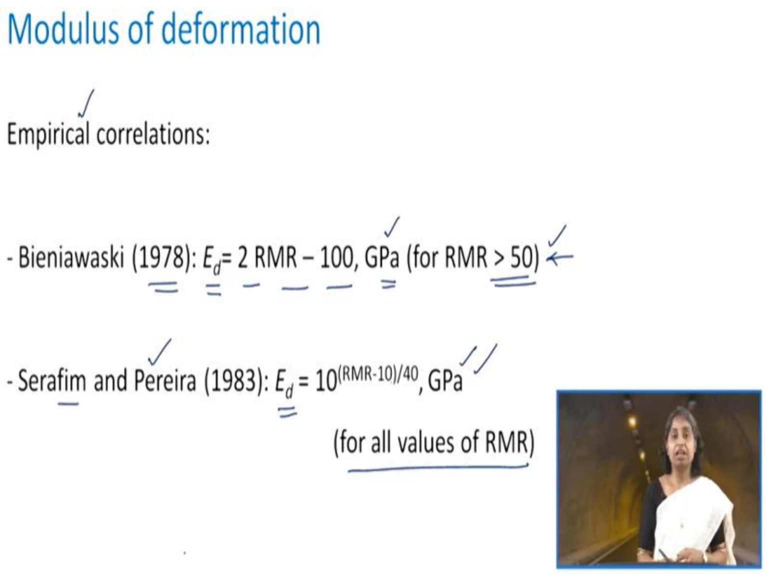

There are few empirical correlations which are also available, so modulus of deformation as per Bieniawski in 1978:

$$E_d = 2RMR - 100, GPa\ (for\ RMR > 50)$$

We need to be careful about the units because here, we are dealing with the empirical correlations. Now, this correlation is applicable when the rock mass has RMR greater than 50.

In 1983 another empirical correlation was given by Seraphim and Pereira and this is one of the most commonly adopted commonly used empirical correlations where the modulus of deformation is given as:

$$E_d = 10^{(RMR-10)/40}, GPa\ (for\ all\ values\ of\ RMR)$$

Again, the unit here is GPa, and this is applicable for all values of RMR. So please remember these are some simple expressions where you if you have the rock mass rating of the rock mass, then you can get the idea about the modulus or deformation of the rock mass.

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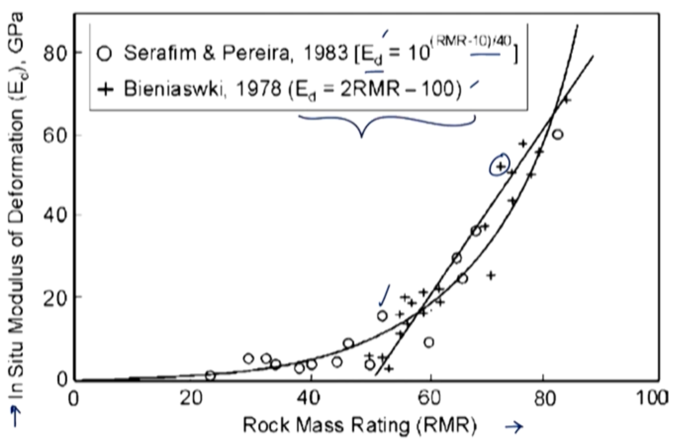
Modulus of deformation



Correlation between E_d and RMR (Singh & Goel, 2011)

Now, if you plot all the data points derived from these 2 empirical correlations, this is what is the curve looks like in the space that is in situ modulus deformation versus the RMR. So, this has been adopted from this reference which I gave you in the first class only. So here, the circular points they are representing the outcome of the curve E_d = 10 to the power RMR -10 by 40 and the plus sign which are these signs they represent the modulus of deformation and the RMR relationship as per this equation that is E_d = 2 RMR-100.

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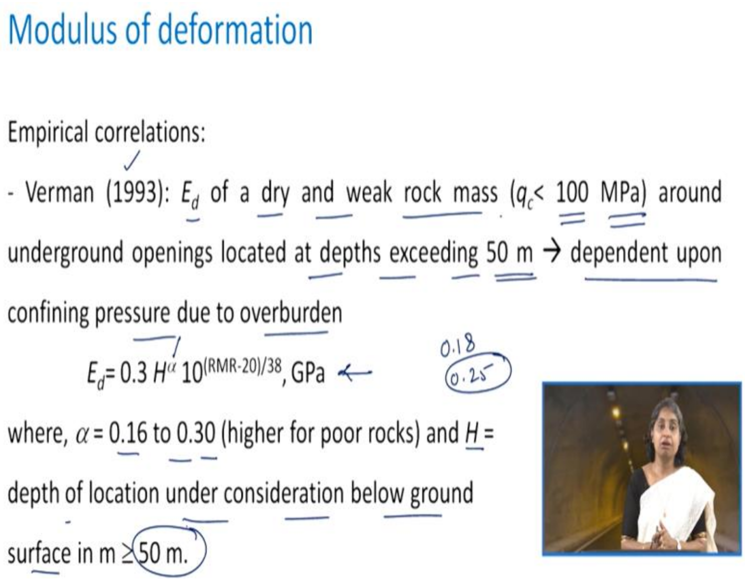

Another correlation which was given by Verman in 1993. So, this was applicable for the modulus of deformation of a dry and weak rock mass which has the UCS of the rock as less than 100 MPa around the underground opening and located at the depths exceeding 50 meters. So, it was dependent upon the confining pressure due to the overburden, and they came out with this expression:

$$E_d = 0.3H^{\alpha}10^{(RMR-20)/38}, GPa$$

Where this α was 0.16 to 0.3, and it will be higher for poor rock. So, that means if there are two values of α let us say that is 0.18 and another one is say, 0.35.

So, which one will be poor as compared to the other one? It will be this which has the higher value of α and H be the depth of location under consideration below the ground surface, or we can call this as the overburden depth, and that should be more than 50 meters. So, these empirical correlations, which are developed on the basis of various test results the observations in the field they cannot be used in general for all type of situation. The reason being that these have been developed for particular situation, and therefore their applicability also becomes to those types of situations.

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Allowable bearing pressure

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

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4	Angle of internal friction of rock mass	> 45°	35-45°	25-35°	15-25°	< 15°
5	Allowable bearing pressure (t/m^2): 12 mm foundation settlement	600-440	440-280	280-135	135-45	45-30
6	Safe cut slope (°)	> 70	65	55	45	< 40

Coming to the next category, which is related to allowable bearing pressure, so now you need to focus on the serial number 5. You know that when we have any foundation, the foundation should be safe in shear as well as in case of the settlement. The settlement should be within the permissible limit. Now, there are many situations where the foundation may be safe in shear but fails in settlement.

So, in such situation it is the settlement criteria which govern the bearing capacity of the foundation, and therefore we call that as allowable bearing pressure. So, here we are talking about the allowable bearing pressure in turn per meter square corresponding to 12 mm of foundation settlement, so these are related to 12 mm of foundation settlement. Please remember this. So, for the case of the rock classes 1 to 5, see how the range of allowable bearing pressure varies.

In case of the very good quality rock mass, the allowable bearing pressure varies in between 440 ton per meter square to 600 ton per meter square. However, in case of the very poor quality, it is as low as 30 to 45 ton per meter square. So, as the quality of the rock mass degrades with the reduction in the value of RMR, there is going to be the reduction in the allowable bearing pressure of the footing as well.

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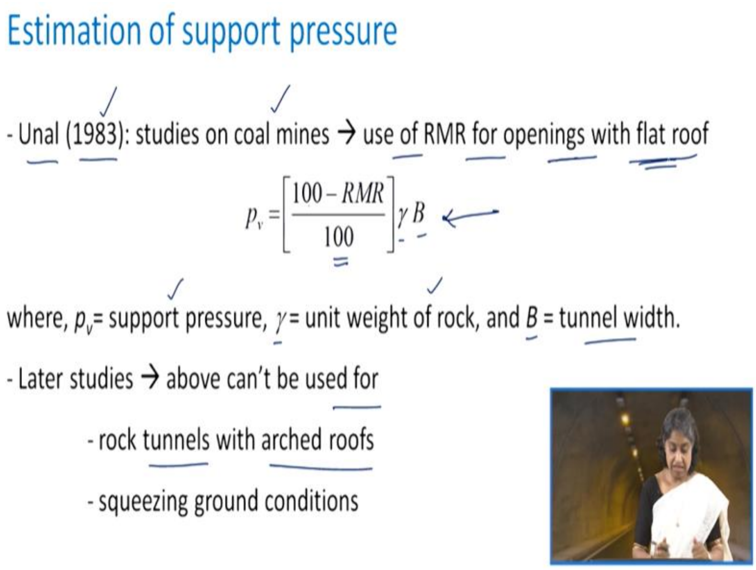

Coming to the next category, which is the support pressure that is extremely important with reference to the underground excavation. So, this Unal in 1983, he conducted lot of studies on coal mines, and then he recommended the use of RMR for openings with a flat roof and he mentioned that the vertical support pressure can be defined as:

$$p_v = \left[\frac{100 - RMR}{100}\right]\gamma B$$

Where, this P_v is the support pressure, γ be the unit weight of rock, and B is the tunnel width. Later studies which were conducted afterwards they mentioned that this equation cannot be used for the rock tunnels with arched roofs or they cannot be used in squeezing ground conditions. So, as I mentioned that since this is also based upon these studies on coal mines for openings with flat roof, so it has its limitation as far as the application is concerned.

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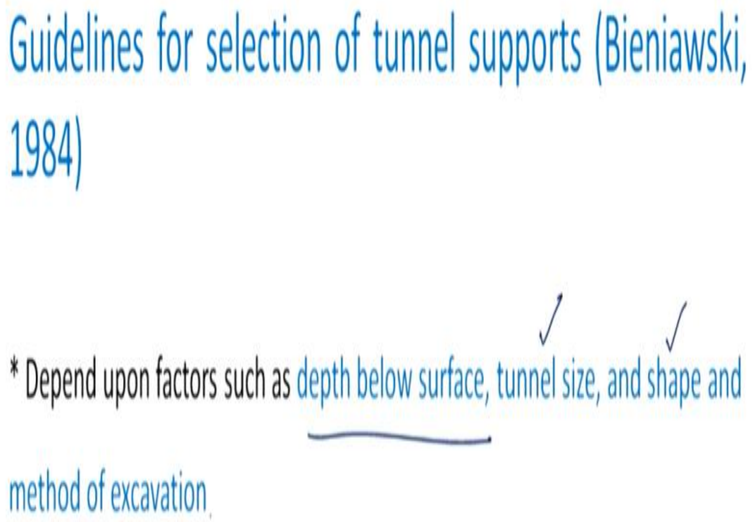

What are the various guidelines for the selection of tunnel supports? Then so, we are going to discuss some of these guidelines, which were given by Bieniawski in 1984. So, these depend upon the factors such as depth below the surface, tunnel size and shape, and also the method of excavation, whether we had gone for the full-face excavation or benching and heading or any other thing.

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Guidelines for selection of tunnel supports (Bieniawski, 1984)

Rock mass class	Excavation	Supports		
		Rock bolts (20 mm diameter, fully grouted)	Conventional shotcrete	Steel sets
Very good rock RMR = 81-100	Full face; 3 m advance	Generally, no support required except for occasional spot bolting		
Good rock RMR = 61-80	Full face; 1.0-1.5 m advance, complete support 20 m from face	Locally bolts in crown 3 m long, spaced 2.5 m, with occasional wire mesh	50 mm in crown where required	None
Fair rock RMR = 41-60	Heading and bench; 1.5-3 m advance in heading; commence support after each blast; complete support 10 m from face	Systematic bolts 4 m long, spaced 1.5-2 m in crown and walls with wire mesh in crown	50-100 mm in crown and 30 mm in sides	None

So, let us take a look according to the various rock classes, how the excavation is done and what all are these supports which are recommended. So here in this table, this has been given in detail that when we have the rock mass class as very good rock having RMR varying between 81 to 100, and the excavation is done as full face and only 3 meter in advance. So, when I say full face means the whole excavation is done in one go.

And unsupported length of the excavation can be 3 meters, so in one go, you have the excavation as 3 meters only. So, in this case, various support systems have been listed in the in this table. These include rock bolts, conventional shotcrete, and steel sets. In some of the earlier classes, I showed you some of the pictures of these supports. So now you should be able to connect that what I am discussing with you.

So generally, in this case, no support is required except for occasional spot bolting but, in case if we have the good rock with RMR varying between 61 to 80, we go for the full phase excavation, and of course here, the quality has deteriorate from this class. So, the advance is also reduced, you see tunnel advance is also reduced to 1 to 1.5 meter. So, the complete support 20 meter from the face in this case. If you have the rock bolts, which are 20-meter diameter and fully grouted locally bolts in the crown portion of the tunnel, which are 3 meter long, should be provided. These are spaced at 2.5 meter with occasional wire mesh.

Then, in case you want to go for conventional shotcreting then 50 millimeter should be the thickness of the shotcrete in crown portion wherever it is required, and you do not need to go for the steel sets. In case if you have the fair rock where the RMR varies in between 41 to 100, one is to go for the excavation as heading and benching, and one can advance 1.5 to 3 meter in heading, and one should commence the installation of the support system after each blast.

So, complete support should be 10 meter from the face. So, in this case, if you have the rock bolts so systematic bolts 4 meter long should be provided, which should be spaced 1.5 to 2 meter in crown and walls with wire mesh in crown that is also needed here. In case of the conventional shotcrete, it is the 50 to 100-millimeter thickness of the short crate should be provided in the crown portion and 30 mm thick in the sides. So, this is about rock bolts and the shotcrete, and as far as the steel sets are concerned, they are not needed.

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Guidelines for selection of tunnel supports (Bieniawski, 1984)

Rock mass class	Excavation	Supports		
		Rock bolts (20 mm diameter, fully grouted)	Conventional shotcrete	Steel sets
Poor rock RMR = 21-40	Top heading and bench; 1.0-1.5 m advance in top heading; install support concurrently with excavation 10 m from face	Systematic bolts 4-5 m long, spaced 1-1.5 m in crown and wall with wire mesh	100-150 mm in crown and 100 mm in sides	Light to medium ribs spaced 1.5 m where required

But, in case if you have the poor rock with RMR varying between 21 to 40, you see that you may go for light to medium steel ribs, which are spaced 1.5 meter wherever required. So, in this case, the top heading and benching method of excavation is adopted with the 1-to-1.5-meter advance in the top heading, and one needs to go for the installation of the support system concurrently with excavation 10 meter from the face.

Systematic rock bolts of length 4 to 5 meter should be installed. These are spaced 1 to 1.5 meter in the crown portion and wall with the wire mesh. As far as the conventional shotcrete is concerned, one needs to provide 100 to 150 mm thick shotcrete layer in the crown portion and 100-millimeter-thick shotcrete layer in the side walls of the tunnel.

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Guidelines for selection of tunnel supports (Bieniawski, 1984)

Rock mass class	Excavation	Supports		
		Rock bolts (20 mm diameter, fully grouted)	Conventional shotcrete	Steel sets
Very poor rock RMR < 20	Multiple drifts; 0.5-1.5 m advance in top heading; install support concurrently with excavation; shotcrete as soon as possible after blasting	Systematic bolts 5-6 m long, spaced 1-1.5 m in crown and walls with wire mesh; bolt invert	150-200 mm in crown, 150 mm in sides, and 50 mm on face	Medium to heavy ribs spaced 0.75 m with steel lagging and forepoling if required; close invert

In case if you have very poor rock where RMR is less than 20, then one needs to go for the multiple drift method. Please, right now, you just learn about some of these terms related to the method of excavation little later, I will be explaining you all these methods that what exactly is the difference between multiple drift method, heading and benching method, full phase method all those things we will be discussing.

So, in case if you have the very poor rock mass, one is to go for the multiple drift method for the excavation and advance only 0.5 to 1.5-meter advance in the top heading. You need to install the support concurrently with the excavation and provision of the shotcrete as soon as possible. After the blasting, because what happens is since it is very poor rock mass, immediately upon the excavation, the rock mass starts experiencing the fall of roof wedges or maybe from the side walls.

So, if you provide the shotcrete immediately after the blasting, at least it provides some kind of support and prevents this type of failure. In this case, one needs to go for the systematic rock bolts of 5 to 6-meter length should be spaced 1 to 1.5 meter in crown portion and walls with the wire mesh, and one needs to also provide the bolt invert. For the conventional shotcrete, this is 150 mm to 200 mm in the crown portion, 150 mm in the sides, and 50 mm on the face. As far as the steel sets are concerned, one needs to go for medium to heavy ribs, which are spaced 0.75 meter with steel lagging and 4 poling if it is required, and you need to go for the close invert.

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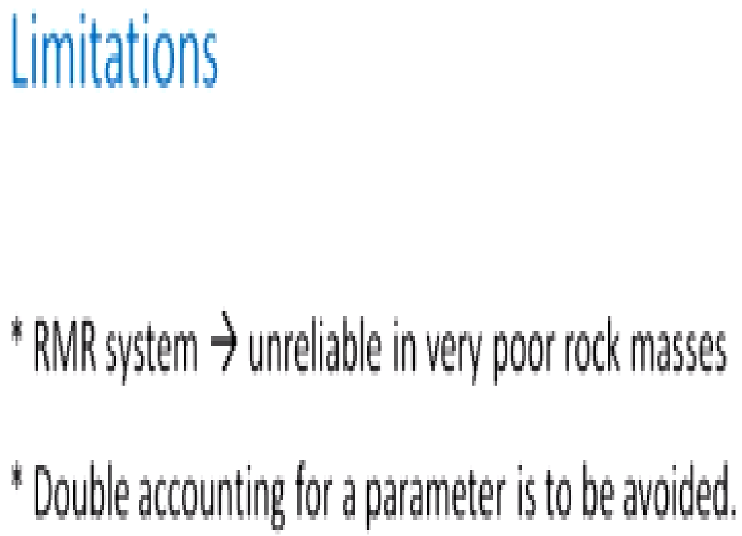

So, as far as the application parts are concerned, we discussed that how we can go for the RMR system to determine the various aspects such as stand-up time, then cohesion and angle of internal friction or the shear strength parameters of the rock mass modulus of deformation support pressure and other applications that we just now learn. But then this system has some serious limitations as well.

These include that it is a very unreliable in case you have very poor rock masses, and then you know how to determine this RMR for the rock mass. We have discussed this in some of the earlier lectures. So, we should be careful that we do not double account for any parameter while evaluating the value of the RMR system. So, in spite of its limitation, this is being used extensively but then wherever it is it has the limitation. We need to use our engineering judgment before we find any application with reference to RMR in such situation.

So, we learnt today that how the rock mass rating system, that is RMR system can be applied to obtain some of the aspects related to the design of underground excavations. So, in the next class, we will learn about the application of another classification system, that is Q-system, but then first, we will learn about some of the tunnel hazards, and then we will try to connect the same to the Q-system. Thank you very much you.