Under Space Technology

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Module No # 07
Lecture No # 31
Application of Rock Mass Classification System: Terzaghi's Rock Load Theory-01

Hello everyone, in the previous class, we discussed about the elastoplastic analysis of the circular tunnel, and we used the Mohr-Coulomb failure criteria to define the property of the rock through which the excavation was made. So, today we are going to start a new chapter which is on the application of various rock mass classification systems in the area of underground space technology. So, today we will take up the first situation that is the classification system defined by Terzaghi's rock load theory.

And then in subsequent classes, we will take up few other classification systems, such as RMR as well as Q-system. So, first of all, let us try to understand that what exactly do we mean by Terzaghi's rock load theory. And before we go to Terzaghi's rock load theory, let us first understand various support systems. I will be discussing these systems in detail, their analysis, and design a little later.

But since I am going to use these terms quite often while discussing the various applications with reference to rock mass classification system. So, I thought that it will be a good idea that at least you should have the knowledge about these various support systems that what exactly these are, and how they look like. So, when we excavate any opening in the rock mass underground opening, then we need to provide the support system based upon the classification of the rock mass surrounding rock mass.

See some of the cases in the earlier classes, we have seen that there can be different types of ground conditions, so based upon that ground condition, we have to choose appropriate support systems. Now, these support systems they include: steel sets, shotcreting provision of rock bolting, or the combination of any of these. So, here I have put some of the pictures which I have taken from the readily available sources, and the references are given in this slide. Here this is only to give you the idea that when I say steel set immediately, this picture should come in your mind, and then you should be able to identify this is what is meant by steel sets.

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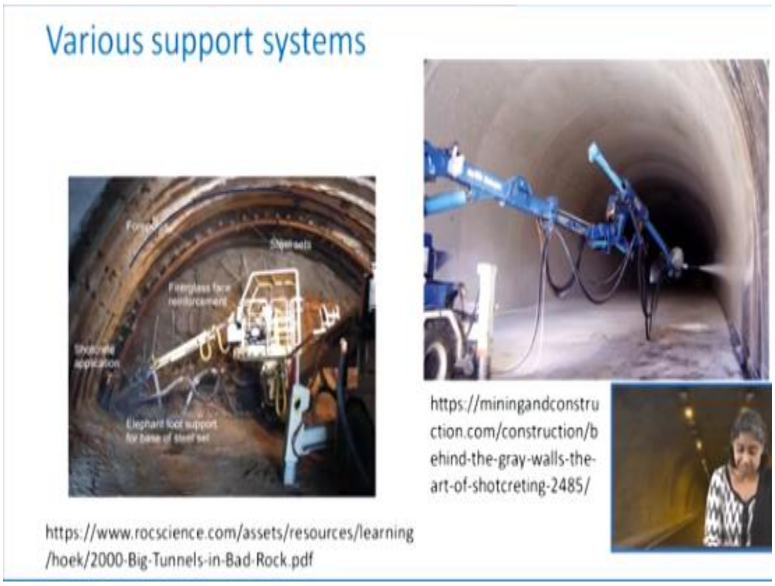

So, you see that the excavation has been made here and see how the steel sets are provided. These are the steel sets, so this is one kind of the support system. So, you have these steel sets having some spacing in the direction, which is along the length of the excavation. Similarly, the second type of support system is called the shotcreting, and here slurry is put on the surface, which is excavated. So, you can see that here this is the spray through which the slurry is being placed.

And if you just see this part, this is the portion that is how it will look after the application of shotcreting. So, this slurry is of cement plus some aggregate and the water. So, this is designed we will be discussing all these things in detail little later.

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So, the third one is the rock bolts, and here you can see that in this picture, there is a machine. This is what is called as rig. And you can see that the bolts are there, and the rig it goes to the particular area where you want to install the rock bolts, and in this particular way, it can be installed. So basically, what rock bolt does is that it stitches the rock mass wherever there is the failure zone.

And there are various types of rock bolts which are available. What exactly is their mechanism to resist the deformation or to stabilize the rock mass surrounding the excavation? All these things we will learn little later. So, for the time being, you should know what I mean by shotcreting? What I mean by provision of steel sets? And what I mean by provision of rock bolts?

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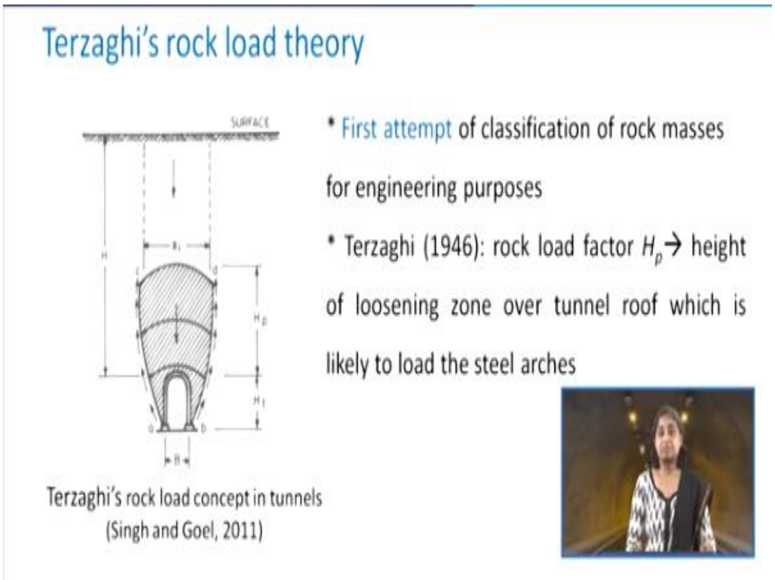

Now let us learn about the Terzaghi's rock load theory. So basically, it was the first attempt of classification of the rock masses for engineering purposes. There were many, but then they were not used for engineering purposes. So basically, when Terzaghi proposed this theory in 1946, it was the first one for engineering purposes. So, Terzaghi defined the rock load factor H_p which was defined as the height of the loosening zone over the tunnel roof, which is likely to load these steel arches.

So, take a look here. This is the excavation because the excavation is made some portion of the rock which is in the surrounding area of this cavity is going to be loosened. So, let us say that from the top of this opening, H_p is the extent up to which there is going to be the loosening zone over the tunnel roof, so this is what is defined as the rock load factor. Now, what should be the value of these rock load factor?

So, this will depend upon the type of the rock mass here through which the excavation is made. So first, Terzaghi defined those rock types or rock mass types, and then accordingly, he prescribed the different values of H_p corresponding to each of those rock load classes.

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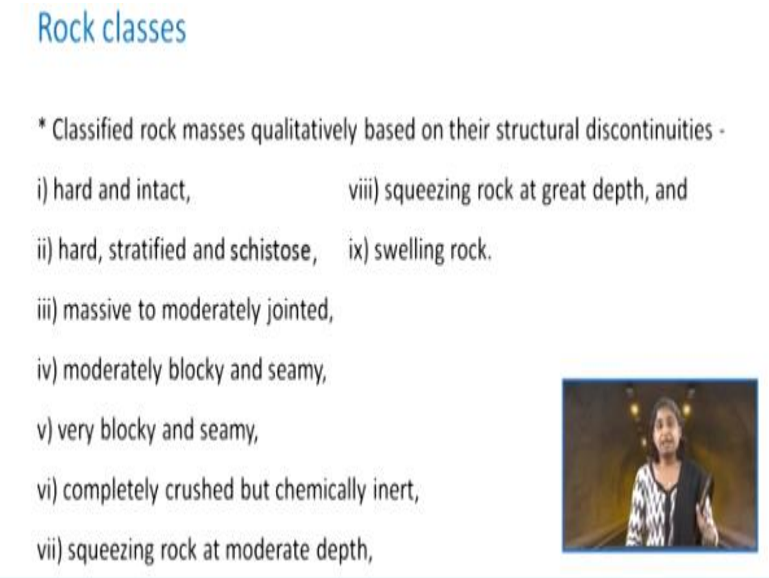

So, as I mentioned, he classified the rock masses qualitatively based on their structural discontinuity only. So, here RQD, UCS, and other factors such as the joint orientation, joint condition, all those things they are not coming into picture. So, this classification was made only in the qualitative manner only based on their structural discontinuities.

So, the first class was hard and intact rock mass. Then you have hard stratified and schistose, the third category called as massive to moderately jointed, fourth one as moderately blocky and seamy, fifth was very blocky and seamy, then sixth one is completely crushed but chemically inert. Then comes the seventh one which was defined as, it is the squeezing rock at moderate depth, followed by another category which was defined as a squeezing rock at grade depth.

And finally, the swelling rock, we have little idea about the swelling ground condition and squeezing ground condition, so that one and this one are the same.

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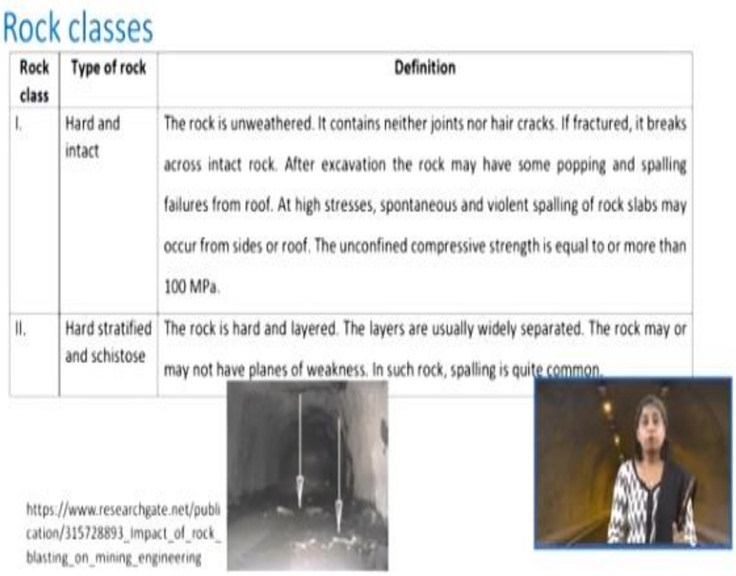

Rock classes

Rock class	Type of rock	Definition
I.	Hard and intact	The rock is unweathered. It contains neither joints nor hair cracks. If fractured, it breaks across intact rock. After excavation the rock may have some popping and spalling failures from roof. At high stresses, spontaneous and violent spalling of rock slabs may occur from sides or roof. The unconfined compressive strength is equal to or more than 100 MPa.
II.	Hard stratified and schistose	The rock is hard and layered. The layers are usually widely separated. The rock may or may not have planes of weakness. In such rock, spalling is quite common.

So, based upon the rock class and the type of rock these were defined again, this definition is going to be qualitative only. So, for the first rock class, the type of rock was hard and intact, and what was the definition? So, in this case, the rock is unweathered. It contains neither the joints nor the hair cracks, but if it is fractured, it breaks across the intact rock. Now, after the excavation, the rock may have some popping and spalling failure from the roof.

At high stresses, there is going to be the spontaneous and violent spalling of rock slabs which may occur from the side walls of the excavation or maybe the roof. And in such situation the UCS value is equal to or more than 100 MPa. Now there is the term called spalling. What exactly do you mean by this? So here I have pasted a picture, so you can see that how the surface of the excavated rock mass kind of it gets chipped off from the surface, and then it just falls below.

So, you see that from this region it has fallen here similarly here so this is what we call as spalling. Then the second raw class has the hard-stratified and schistose types of rock. In this case, the rock is hard and layered. The layers are usually quite widely separated. In this case, the rock may or may not have the planes of weakness, and in such rocks, spalling is very quite common.

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Rock classes

Rock class	Type of rock	Definition
III.	Massive moderately jointed	A jointed rock. The joints are widely spaced. The joints may or may not be cemented. It may also contain hair cracks but the huge blocks between the joints are intimately interlocked so that vertical walls do not require lateral support. Spalling may occur.
IV.	Moderately blocky and seamy	Joints are less spaced. Blocks are about 1 m in size. The rock may or may not be hard. The joints may or may not be healed but the interlocking is so intimate that no side pressure is exerted or expected.

The third category includes massive moderately jointed type of rock. This is of course a jointed rock. Where joints are widely spaced, these may or may not be cemented. And it may also contain hair cracks, but the huge blocks between these joints are interlocked so that the vertical walls do not require the lateral support. So basically, as far as the side walls are concerned, they may not require any lateral support because of this reason that the joints are intimately interlocked, so in this case, spalling may occur.

Coming to the fourth type of the rock class, which is defined as moderately blocky and seamy type of rock. So, in this case, these joints are less spaced blocks are about 1 meter in size, and these types of rocks they may or may not be hard. So, the joints may or may not be healed, but the interlocking is so intimate that no side pressure is expected or exerted. So that means that practically there will not be the requirement of any support on the side walls.

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Rock classes

Rock class	Type of rock	Definition
V.	Very blocky and seamy	Closely spaced joints. Block size is less than 1 m. It consists of almost chemically intact rock fragments which are entirely separated from each other and imperfectly interlocked. Some side pressure of low magnitude is expected. Vertical walls may require supports.
VI.	Completely crushed by chemically intact	Comprises chemically intact rock having the character of a crusher run aggregate. There is no interlocking. Considerable side pressure is expected on tunnel supports. The block size could be few centimeters to 30 cm.

Fifth rock class has very blocky and semi-type of rock. What do we mean by this qualitatively? These include closely spaced joints. In this case block size is less than 1 meter. And it consists of almost chemically intact rock fragments which are entirely separated from each other and imperfectly interlocked. So, you just compare this raw class with the previous one, that is the fourth one, and you will realize that how I this has been kept in the separate category.

Then some side pressure of low magnitude is expected, and therefore the vertical walls of the excavation they may need support system. Coming to the sixth type of rock class which is having the completely crushed type of rock, but these are chemically intact. So, here these comprise chemically intact rock having the character of a crusher-run aggregate. There is no interlocking, and considerable side pressure is expected on the tunnel support. And in this case, the block size could be a few centimeters to 30 centimeters.

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Rock classes

Rock class	Type of rock	Definition
VII.	Squeezing rock-moderate depth	Squeezing is a mechanical process in which the rock advances into the tunnel opening without perceptible increase in volume. Moderate depth is a relative term and could be up to 150 m to 1000 m.
VIII.	Squeezing rock-great depth	The depth may be more than 150 m. The maximum recommended tunnel depth is 1000 m (2000 m in very good rocks).

The seventh rock class has the squeezing rock at moderate depth. You know that the squeezing is a mechanical process in which the rock advances into the tunnel opening without any perceptible increase in the volume. So basically, if you excavate the opening, then on its own, it will have the convergence, or the rock mass moves in the cavity. So, moderate depth is a very relative term, and it could be up to, let us saying 150 meter to 1000 meter.

So, you see, the range is so high. So, one needs to be extremely careful when such terms they come into the picture or in the situation. So accordingly, you have to use your engineering judgment while deciding upon the adequate support system. Coming to the eighth type of rock class, there it is defined by the squeezing rock at great depth. Now the depth may be more than

150 meter, but the maximum recommended tunnel depth is 1000 meter and sometimes 2000 meter in case if you have very good rock at the site.

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Rock classes

Rock class	Type of rock	Definition
IX.	Swelling rock	Swelling is associated with volume change and is due to chemical change of the rock usually in presence of moisture or water. Some shales absorb moisture from air and swell. Rocks containing swelling minerals such as montmorillonite, illite, kaolinite and others can swell and exert heavy pressure on rock supports.

The next category and the last one includes the swelling rock. This is associated with volume change and is due to chemical change of the rock, which is usually takes place in the presence of moisture or water. So, what happens is let us say that you have some shale type of rock at the site, so what happens is that? In the presence of the water, such type of rocks like shales, they absorb the moisture from air, or if they are exposed to the water then, of course, they will be absorbing the moisture.

And then they swell that means their volume increases, so any rock containing the swelling minerals such as montmorillonite, illite, kaolinite, and other minerals they can swell and exert very heavy pressure on rock supports. So, you see that the more the pressure on the rock support system and you have to provide more and more support system to handle that kind of pressure that is coming on to them. So, we will learn all these things that how to design the support system, which one should be appropriate in which case. If you have the support pressure may be at roof or at the side wall. All those things we will discuss in detail in this course but a little later.

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When I say squeezing rock so basically, we refer to the squeezing ground condition. So basically, it is the ground condition and not the rock. But somewhere in the literature, many places you will see that they say that over there it is squeezing rock. So, what they are referring to is that it is the squeezing ground condition. A jointed and the weak rock mass that fails at high stress and squeezes into the tunnel; that is what we say is the squeezing ground condition.

And in one of our earlier lectures, we already have seen that, what is the difference between swelling and squeezing ground conditions. So, you can refer back to that particular lecture to understand this better if you do not remember now.

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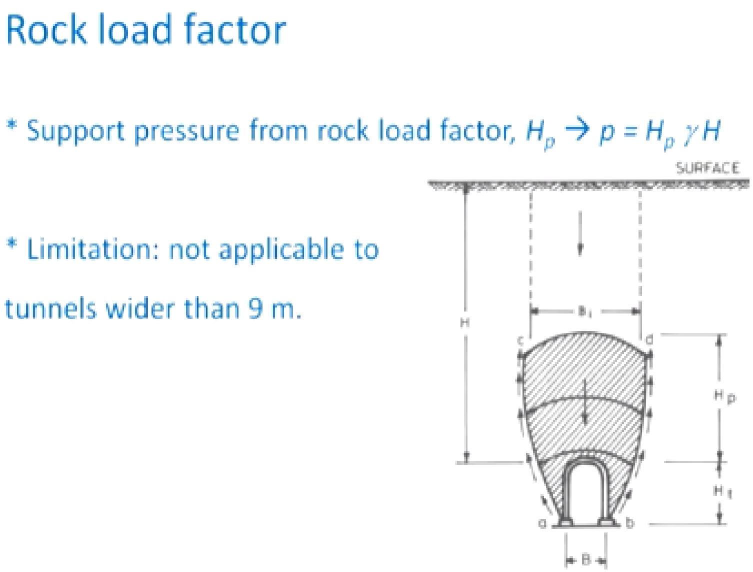

Now, coming to the rock load factor, so basically the support pressure was defined by Terzaghi in terms of the rock load factor. Why this support pressure is required? Because until and unless we know this support pressure, we will not be able to design the adequate support system. So, if somebody wants to use the Terzaghi's rock load theory, in that case, the support pressure (p) is defined in terms of the rock load factor H_p and is given by this expression which is:

$$p = H_p \gamma H$$

So, you can see what is H_p? That is the rock load factor which I already explained that how this is defined, γ is the unit weight of the rock mass here. And H is the depth of the overburden. So, you see what is this from the ground surface to the top of the tunnel, whatever is this height that is, what we call as the overburden. The limitation of the use of this rock load factor is that this theory is not applicable to the tunnels which are wider than 9 meter.

So, later on, people have modified this theory to overcome some of such limitations of the Terzaghi's rock load theory, that also we will see in this lecture.

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Rock load factor

Terzaghi (1946) Rock load in tunnels within various rock classes (Singh and Goel, 2011)

Rock class	Rock condition	Rock load factor, H_p	Remarks
I.	Hard and intact	Zero	Light lining required only if spalling or popping occurs
II.	Hard stratified or schistose	0-0.5B	Light support mainly for protection against spalling. Load may change erratically from point to point
III.	Massive moderately jointed	0-0.25B	No side pressure
IV.	Moderately blocky and seamy	0.25B- 0.35 (B+H_t)	No side pressure

So, what should be the value of rock load factor because until unless we know that, we will not be able to get the support pressure and will not be able to design the support system. This is what was given by Terzaghi that corresponding to each rock class, like 1, 2 up to the 11 rock classes. So, these different values of rock load factors corresponding to each rock class were defined. Now let us take them one by one, and then here this table also includes the remarks section, which gives us the idea that in case if this is the type of the rock, then what may be the appropriate support system?

So, if you have the rock class 1 it is the rock condition is hard and intact, and in this case, you will have 0 value of rock load factor. And that means that there is no support pressure which is exerted on the either the side wall or the roof, but in case if spalling or popping occurs, then light lining may be required in such cases. If you have the second type of the rock class, which is hard stratified or schistose, then this rock load factor was taken to be 0 to 0.5 times the B.

Now what is this B? Take a look here this is the width of the opening that means this dimension, so basically this H_p was defined in terms of this B and also the height of the excavation H_t in some of the rock classes. Coming to the third one which is having the massive moderately jointed rock, the rock load factor is 0 to 0.25 times B, and there is not going to be any side pressure similar is the case as far as the side pressure is concerned for the fourth type of rock class. Which is defined as moderately blocky and seamy in this case, the rock load factor takes the value between 0.25 B to 0.35 times B + H_t.

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Rock load factor

Rock class	Rock condition	Rock load factor, H_p	Remarks
V.	Very blocky and seamy	(0.35-1.10) $(B+H_t)$	Little or no side pressure
VI.	Completely crushed	1.10 $(B+H_t)$	Considerable side pressure. Softening effects of seepage towards bottom of tunnel require either continuous support for lower ends of ribs or circular ribs
VII.	Squeezing rock-moderate depth	(1.10-2.10) $(B+H_t)$	Heavy side pressure, invert struts required. Circular ribs are recommended

Coming to the fifth type of rock class which is defined by very blocky and seamy rock condition in this case, very little or no side pressure is there on the side walls, so the rock load factor value was ranging between 0.35 to 1.1 times B + H_t. Then when there is the completely crushed type of rock condition in that case, it is 1.1 times B + H_t in this case, considerable side pressure will occur.

And the softening effects of seepage towards the bottom of the tunnel require either continuous support for lower end of ribs or the circular ribs. So, when I say these ribs, these connect to the steel sets that I showed you in the second slide of this particular lecture. Then if we have the squeezing rock at moderate depth, that range in which the rock load factor varies includes 1.1 to 2.1 times B + H_t.

In this case, there is occurrence of heavy side pressure and invert struts are needed, and circular ribs are recommended. So, as far as this remark column is concerned simultaneously, we are getting the idea that what will be the magnitude of the side pressure. And what will be the appropriate type of the support system?

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Rock load factor

Rock class	Rock condition	Rock load factor, H_p	Remarks
VIII.	Squeezing rock-great depth	(2.10-4.50) $(B+H_t)$	Heavy side pressure, invert struts required. Circular ribs are recommended
IX.	Swelling rock	Up to 250 ft. (80 m) irrespective of the value of $(B+H_t)$	Circular ribs are required. In extreme cases, use of yielding support recommended.

Note: roof of the tunnel: assumed to be located below water table. If it is located permanently above the water table, then the values given for classes IV to VI can be reduced by 50%.

Then, coming to the eighth type of rock class there, you have the squeezing rock at great depth. Here the rock load factor varies between 2.1 to 4.5 times B + H_t heavy side pressure invert struts. They are required, and in this case, also the circular ribs are recommended. In case of the swelling rock condition, we have this as up to 250 feet or 80 meters irrespective of the value of B + H_t. So here this rock load factor that is H_p it will be up to 80 meters.

So, in this case, circular ribs are required, and in extreme cases, the use of yielding supports they are also recommended. Now uniquely take a note of some of the things which are mentioned here at the bottom of this table that, as far as roof of the tunnel is concerned, it is assumed to be located below the water table. So, all these values of the rock load factor they are given having this assumption in mind that the water table that the roof of the tunnel is located below the water table.

Now, if the roof is located permanently above the water table, then the values which are given for classes 4 to 6 these can be reduced by 50%. So, this modification should be made if the roof is located permanently above the water table.

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Rock load factor

Deere et al. (1970): modified Terzaghi's classification system by introducing RQD as the lone measure of rock quality

Terzaghi's rock load concept as modified by Deere et al. (1970)(Singh and Goel, 2011)

Rock class and condition	RQD (%)	Rock load factor, H_p	Remarks
I. Hard and intact	95-100	Zero	Same as for Terzaghi (1946)
II. Hard stratified or schistose	90-99	0-0.5*B*	Same as for Terzaghi (1946)
III. Massive moderately jointed	85-95	0-0.25*B*	Same as for Terzaghi (1946)

Then, as I mentioned that this, Terzaghi's rock load theory has the limitations, so some of the other research workers they modified by introducing the RQD as the lone measure of rock quality. So here is going to be one of such modification that I am going to discuss with you that was given by Deere et al. in 1970. So, for various types of rock classes and the conditions so that has been mentioned.

So, the first one, such as the rock class and the text gives you the condition, and the corresponding value of RQD in percentage has been given, and the rock load factor is also given. And some of the remarks are there, so in these 3 rock classes, that is 1, 2, and 3, the rock load factors remain the same as it was there for Terzaghi's rock load theory which was proposed in 1946. So, no change is going to be there even if some modifications are took place by inclusion of RQD.

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Rock load factor

Rock class and condition	RQD (%)	Rock load factor, H_p	Remarks
IV. Moderately blocky and seamy	75-85	0.25*B* – 0.35 $(B+H_t)$	Types IV, V, and VI reduced by about 50% from Terzaghi values because water table has little effect on rock load
V. Very blocky and seamy	30-75	(0.2–0.6) $(B+H_t)$	Same as above
VI. Completely crushed	3-30	(0.6–1.10) $(B+H_t)$	Same as above
VIa. Sand and gravel	0-3	(1.1–1.4) $(B+H_t)$	Same as above

Coming to the next category, that is when you have the fourth rock class, which corresponds to the RQD values between 75 to 85%. Then, in that case, the rock load factor is defined by this that is varying between 0.25 B to 0.35 B + H_t. In this case, types 4, 5, and 6 they are reduced by about 50% from Terzaghi's values because water table has very little effect on the rock load in case of rock class 5, 6, and 6a, where you have sand and gravel.

So, in all these 3 the corresponding values of RQD are given in this table, and so is the rock load factor H_p and the remarks are going to be same as that for the class 4 that is, types 4, 5, and 6 they will be reduced by about 50% from Terzaghi's values.

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Rock load factor

Rock class and condition	RQD (%)	Rock load factor, H_p	Remarks
VII. Squeezing rock at moderate depth	NA	(1.10-2.10) $(B+H_t)$	Same as for Terzaghi (1946)
VIII. Squeezing rock at great depth	NA	(2.10-4.50) $(B+H_t)$	Same as for Terzaghi (1946)
IX. Swelling rock	NA	Up to 80 m irrespective of the value of $(B+H_t)$	Same as for Terzaghi (1946)

Note: blast and machine excavated tunnels were distinguished. Guidelines were proposed for selection of steel set, rock bolts, and shotcrete supports for 6-12 m diameter tunnels in rock.

Coming, to the squeezing rock at the moderate depth, so basically, in this case RQD is not applicable. So, in this case, the rock load factor expression remains the same as that was for Terzaghi 1946. And similar is the situation for rock class 8 and 9 that is squeezing rock at great depth and swelling rock in this case, also RQD is not applicable. So, in this case of the swelling rock, let us stay take, for example, that in this case, this rock load factor will be up to 80 meters irrespective of whatever is the value of B + H_t.

Now, one needs to take the note here that blast and machine excavated tunnels were distinguished in this because when the excavation is made using blast, there is more disturbance in the surrounding rock mass and therefore, the rock load factor will be influenced but if you have gone for the excavation using the machine-like tunnel boring machine. Then, in that case, the disturbance is relatively much lower.

So, all those things were distinguished here. So, the guidelines were proposed for the selection of steel sets, rock bolts, and shotcrete support for 6-to-12-meter diameter of the tunnels in rock.

Now what all are those guidelines we will see in the next class. So, what we learned today was that how the rock mass classification system given by Terzaghi's rock load theory can be applied in case of the design of underground excavation.

And we saw that based upon the 9 types of rock classes how we can define the support pressure based upon the rock load factor. And how we can get the some kind of suitable support system for the roof as well as the side wall. So, what all are those guidelines that I just now mentioned to you that we will learn in the next class. Thank you very much.