Under Space Technology
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Module No # 07
Lecture No # 32
Application of Rock Mass Classification System: Terzaghi's Rock Load Theory-02

Hello everyone, in the previous class, we started our discussion on the application of rock mass classification system to the design and analysis of underground excavations. And in that one, the first we started with the Terzaghi's rock load theory where we saw various types of the support system. Then, how Terzaghi defined the various rock classes and corresponding to that what were the different values of rock load factor.

And based upon the rock load factor value, we decided that what will be the appropriate support system. So, there I mentioned to you that based upon the type of the excavation in the sense that whether the excavation was made using blasting or using a tunnel boring machine, there were various guidelines which were there. So, let us discuss those guidelines but before that just to recap some of the things that we discussed in the previous class.

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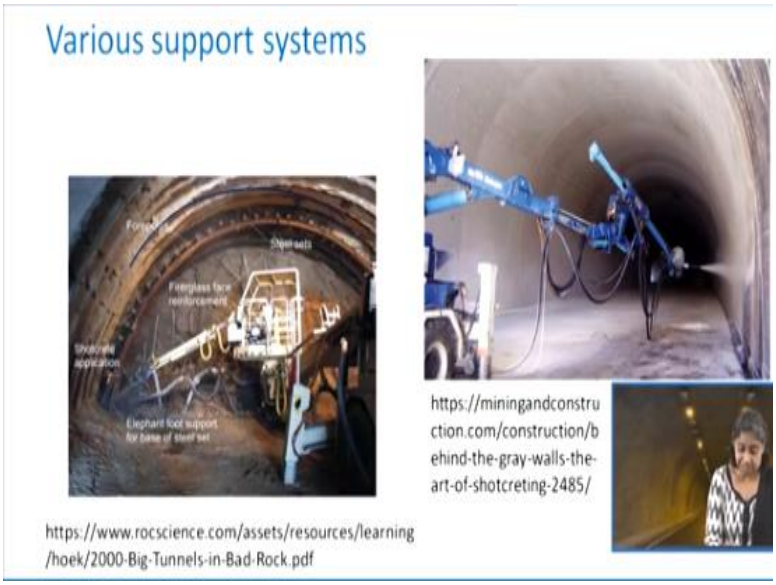

So, we had this type of the support system. I mentioned to you that here is the steel set. This one is shotcreting.

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Various support systems

https://miningandconstruction.com/news/atlas-copco-launches-compact-rock-bolting-rig-2433/

And this is the rock bolting which is in progress using a rig.

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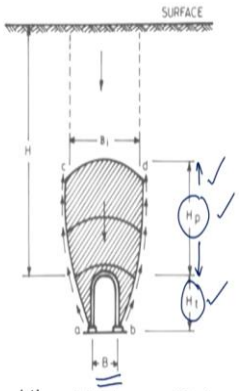
Terzaghi's rock load theory



Terzaghi's rock load concept in tunnels
(Singh and Goel, 2011)

* First attempt of classification of rock masses for engineering purposes

* Terzaghi (1946): rock load factor H_p → height of loosening zone over tunnel roof which is likely to load the steel arches

Then this was the Terzaghi's rock load theory which was given by Terzaghi in 1946. There he defined the rock load factor Hp as the height of loosening zone over tunnel roof, which is likely to load the steel arches and has been shown here in this figure that is this is the dimension. H_t be the height of the excavation, B be the width of the excavation and accordingly, based upon these values of B, H, and H_t. We had the various categories and the range of this rock load factor for different types of rock classes.

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Rock load factor

Guidelines for selection of steel sets for 6-12 m diameter tunnels in rock (Singh and Goel, 2011)

Rock quality	Construction method	Steel sets		Rock bolts		Shotcrete		Additional supports
		Weight of steel sets	Spacing	Spacing of pattern bolt	Additional requirements	Total thickness (cm) Crown	Sides	
Excellent RQD > 90	Boring machine	Light	None to occasional	None to occasional	Rare	None to occasional	None	None
	Drilling & blasting	Light	None to occasional	None to occasional	Rare	None to occasional	None	None
Good RQD 75-90	Boring machine	Light	Occasional to 1.5 to 1.8 m	Occasional to 1.5 to 1.8 m	Occasional mesh and straps	Local application 5 to 7.5 cm	None	None
	Drilling & blasting	Light	1.5 to 1.8 m	1.5 to 1.8 m	Occasional mesh and straps	Local application 5 to 7.5 cm	None	None

So, how to decide the selection of steel sets for 6 to 12-meter diameter tunnels in rock based upon the construction method of the tunnel? So, in case if the rock quality is excellent, that is represented by the value of RQD being greater than 90, and you can see that for each type of rock quality here, we have divided them into 2 rows, one corresponds to the boring machine and the second one corresponds to drilling and blasting.

So, the three types of support systems were identified that is steel sets, rock bolts, and shotcrete. And in case if the additional supports are required, so that have been entered into the last column under the heading additional supports. So, let us come to the first type of rock quality which was excellent then, we have the first row corresponding to the excavation that is made by a tunnel boring machine

So, in this case, the lightweight steel sets are to be provided, and the spacing is none to occasional. In case if it is rock bolts, the spacing of the pattern bolt is none to occasional and additional requirement is rare. And in case of the shotcrete again in the crown portion of the tunnel, that is if this is the tunnel, this is the crown portion that is top and the bottom one is invert, and these are the sides.

So, in the sides, none shotcreting is needed, and there is no need for the additional support. So, if we take the other method, that is drilling and blasting method, in that case, everything remains the same. So that means that when you have the excellent rock quality, whether you go for the use of tunnel boring machine or drilling and blasting, it does not make much difference as far as the decision on the various support systems are concerned.

Then the second type of the raw quality is good, which is defined by RQD varying in between 75 to 90. So, again here we have the two construction methods, one is the boring machine, and the another one is drilling and blasting and the corresponding requirement for the 3 types of the support system have been given in these 2 rows. For example, when we use the tunnel boring machine, we need the light weight of these steel sets, and the spacing is going to be occasional or 1.5 to 1.8 meters in case of the rock bolts.

Similar situation, an additional requirement in case of the rock bolts include the occasional mesh and straps. Now in case of the shotcrete, there is the need for the local application of the shotcrete having thickness of 5 to 7.5 centimeters. And in the side, there is no need for the provision of the shotcrete, and of course, no additional supports are needed. Then coming to drilling and blasting again, we need the light steel sets spacing is going to be 1.5 to 1.8 meter.

In case of rock bolts, it is the spacing of the pattern bolt is 1.5 to 1.8 meter. In this case, also we need the occasional mesh, and the straps for the shotcrete one needs to go for the local application with the thickness of the shotcrete varying from 5 to 7.5 centimeters and in the side, you do not need to provide any shotcrete.

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Rock load factor

Guidelines for selection of steel sets for 6-12 m diameter tunnels in rock (Singh and Goel, 2011)

Rock quality	Construction method	Steel sets		Rock bolts		Shotcrete		Additional supports
		Weight of steel sets	Spacing	Spacing of pattern bolt	Additional requirements	Total thickness (cm)		
						Crown	Sides	
Fair RQD 50 to 75	Boring machine	Light to medium	1.5 to 1.8 m	1.2 to 1.8 m	Mesh and straps as required	5-10 cm	None	Rock bolts
	Drilling & blasting	Light to medium	1.2 to 1.5 m	0.9 to 1.5 m	Mesh and straps as required	10 cm or more	10 cm or more	Rock bolts
Poor RQD 25 to 50	Boring machine	Medium circular	0.6 to 1.2 m	0.9 to 1.5 m	Anchorage may be hard to obtain. Considerable mesh and straps required	10 to 15 cm	10 to 15 cm	Rockbolt as required (1.2-1.8 m center to center)
	Drilling & blasting	Medium to heavy circular	0.2 to 1.2 m	0.6 to 1.2 m	As above	15 cm or more	15 cm or more	As above

Coming to the next category where you have the fair rock quality which is defined by RQD varying from 50 to 75. Again, both the situation using the tunnel boring machine and drilling and blasting has been given here that is light to medium weight of the steel set which is needed, and spacing is 1.5 to 1.8 meter. In case the construction has been done using the tunnel boring machine and in case if it is done using the drilling and blasting.

So, you see that the spacing is reduced here to 1.2 to 1.5 as compared to the case of the boring machine. Similarly, for the rock bolts, if you just compare the spacing of the pattern bolt, the spacing is less in case of the drilling and blasting method of construction as compared to if the boring machine is used for the construction. So additional requirement for both of these includes mesh and straps as it is required. In case of the application of the shotcrete in the crown portion, you need to provide 5- to 10-centimeter-thick shotcrete layer for the tunnel boring machine.

But in case if the construction has been done using drilling and blasting method, it is 10 centimeter or more. In case of the side walls as far as the shotcreting is concerned, no shotcreting is needed if the construction is done using the tunnel boring machine. But in case if it has been done using drilling and blasting method 10 centimeter or more is needed the additional support that is needed in this case is the rock bolts along with the shotcrete.

In case if you have the poor type of rock quality defined by the RQD in between 25 to 50. Here the weight of these steel sets will be medium, and circular steel sets are needed in case of the construction using tunnel boring machine. But in case if the construction of the excavation is done using drilling and blasting method, then it is medium to heavy steel sets, and of course the circular steel sets are needed.

And again, in this case, you can see that the spacing range is larger and the lower limit of this is less as compared to the lower limit of the spacing in case of the tunnel boring machine. Similar is the situation in case you have the rock bolts so you can compare and get the idea that how based upon the construction method, the requirement of the support system also changes. Now, in this case, the additional requirement for both these situations remains the same.

That is that anchorage may be hard to obtain, and therefore considerable mesh and straps they are needed. Similar is the guideline is given for the shotcreting, and the additional supports in the form of rock bolts are needed with the spacing of the rock bolts as the 1.2-to-1.8-meter center to center.

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Rock load factor

Guidelines for selection of steel sets for 6-12 m diameter tunnels in rock (Singh and Goel, 2011)

Rock quality	Construction method	Steel sets		Rock bolts		Shotcrete		Additional supports
		Weight of steel sets	Spacing	Spacing of pattern bolt	Additional requirements	Total thickness (cm)		
						Crown	Sides	
Very poor RQD<25	Boring machine	Medium to heavy circular	0.6 m	0.6 to 1.2 m	Anchorage may be impossible. 100% mesh and straps required	15 cm or more on whole section	-	Medium sets as required
	Drilling & blasting	Heavy circular	0.6 m	0.9 m	As above	15 cm or more on whole section	-	Medium to heavy sets as required
Very poor Squeezing and swelling ground	Both methods	Very heavy circular	0.6 m	0.6 to 0.9 m	Anchorage may be impossible. 100% mesh and straps required	15 cm or more on whole section	-	Heavy sets as required

Coming to the rock quality with RQD less than 25, that is very poor rock quality. In this case, if the construction has been done using the boring machine the weight of the steel sets, they are medium to heavy, and the circular steel sets are to be provided. In case if it is drilling and blasting, heavy steel sets are needed. So, you see that when we are doing the construction using drilling and blasting lot of disturbance takes place in the area surrounding the excavation or the cavity.

And therefore, in general, larger support systems are needed in case if the excavation is done using the drilling and blasting method. So respective values of the spacing of the pattern bolt additional requirements they are provided here. And as far as the shotcreting is concerned so, in the crown portion, the shotcreting is needed 15 centimeter or more and on the whole section. That means the complete excavation this shotcreting will be needed.

In this case also when the drilling and blasting is done there also it is done for the whole section. Additional supports along with the shotcrete that is, in this case, medium sets are needed, and here a medium to heavy sets are required. Now in case if you have very poor squeezing or swelling ground condition for both the methods, whether you go for the tunnel boring machine or the drilling and blasting method. You will need very heavy weight of these steel sets and the circular steel sets they are needed the spacing is to be provided which is 0.6 meters.

And in case of the rock bolts, it is point 0.6 to 0.9 meter. Then in these cases, anchorage may be just impossible. So, 100% mesh and straps are going to be needed. As far as the shotcreting is concerned 15 centimeter or more on the complete section along with the heavy sets it needed. So, this is how some of the guidelines can help us to decide that what should be the appropriate

support system for two different methods set be like if you are going for the construction of the excavation using a machine or drilling and blasting.

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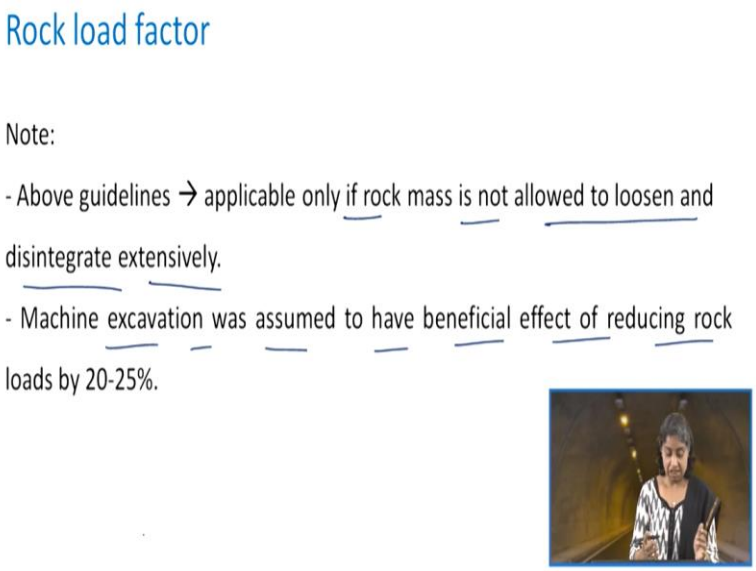

We need to keep that in mind that all these guidelines that we discussed they are applicable only if the rock mass is not allowed to loosen and disintegrate extensively. So, machine excavation was assumed to have the beneficial effect of reducing the rock loads by 20 to 25%. Because of the fact that when we go for the machine excavation, the extent of the loosening zone or loosening mass is less as compared to drilling and blasting method.

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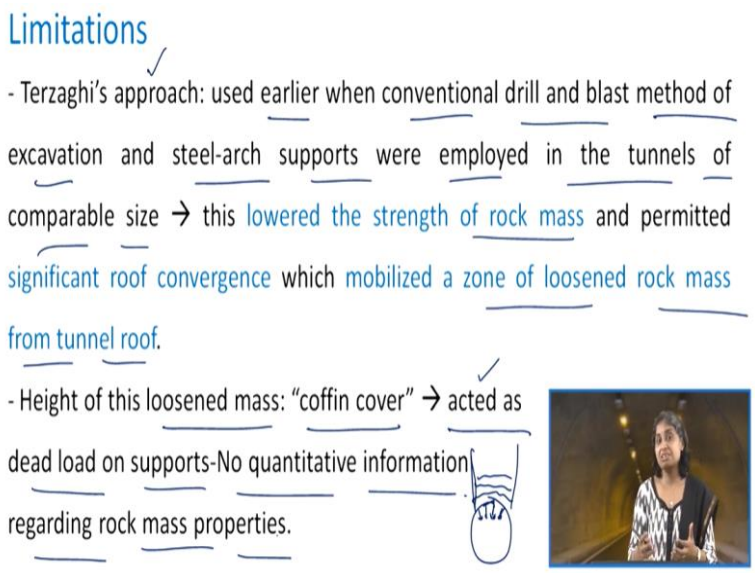

There are limitations related to Terzaghi's approach. It was used earlier when conventional drill and blast method of excavation and steel arch supports were employed in the tunnels of comparable size. So, what happened because of that lowered the strength of the rock mass, and

it permitted the significant roof convergence, which mobilized a zone of the loosened rock mass from tunnel roof.

See, if this is the excavation, let us see, and if this is allowed to the convergence, let us say so what will happen? The moment this surface converges, what happens? Neighboring rock mass it gets loosened, and so the extent of the loosened mass is activated. So, height of this loosened mass which is also called as coffin cover it acted as a dead load on these supports. And since no quantitative information regarding rock mass properties are there.

Because in case of the Terzaghi's approach is it was only the qualitative approach. So therefore, it becomes really difficult so, and it becomes one of the major limitations of Terzaghi's approach.

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So, in spite of this limitation Terzaghi's approach finds its application under the conditions similar to some for which this Terzaghi's approach was developed. So, I mentioned to you that depending upon the size of the excavation, you will be deciding whether the Terzaghi's approach will be applicable or not. So, if those limitations, those assumptions which for which this approach was developed if it is being fulfilled, then Terzaghi's approach can still be applicable.

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Modified Terzaghi's theory for tunnels and caverns

- Singh et al. (1995): compared support pressure measured from tunnels and caverns with estimates from Terzaghi's rock load theory.
- Support pressure in rock tunnels and caverns does not increase directly with excavation size as assumed by Terzaghi (1946) and others.
- This is mainly due to dilatant behavior of rock masses, joint roughness and prevention of loosening of rock mass by improved tunneling technology.

So, as I mentioned to you that some of the research workers, they modified Terzaghi's theories for tunnels and caverns. So, one of such we discussed in the earlier class and the other one that we are going to take up now. This was done by Singh et al. in 1995; what they did. They compare the support pressure measured from tunnels and caverns with estimates from Terzaghi's rock load theory.

So, support pressure in rock tunnels and caverns they do not increase directly with the excavation size as it was assumed by Terzaghi in 1946 and some of those subsequent studies. So, this is mainly due to the dilatant behavior of rock masses joint roughness and prevention of loosening of rock mass by improved tunneling technology.

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Modified Terzaghi's theory for tunnels and caverns

- For those who still wants to use Terzaghi's theory, support pressures can be -

Terzaghi's classification			Classification of Singh et al. (1995)				Remarks
Category	Rock condition	Rock load factor, H_p	Category	Rock condition	Recommended support pressure, MPa		
					p_v	p_h	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
I	Hard and intact	0	I	Hard and intact	0	0	-
II	Hard stratified and schistose	0 to 0.25*B*	II	Hard stratified and schistose	0.0-0.04	0	-
III	Massive, moderately jointed	0 to 0.5*B*	III	Massive, moderately jointed	0.04-0.07	0	-

So, but still, those who want to use Terzaghi's theory. So here is a table that is showing the comparison of the Terzaghi's classification along with the classification of Singh et al., which

was proposed in 1995. So, take a look here for the first category, we had hard and intact rock, and the rock load factor was 0. But in case if we go for the classification of Singh et al. again, the category is the first one drop condition is hard and intact.

In this case, the recommended support pressure that is the vertical and the horizontal P_v is the vertical support pressure P_h is the horizontal support pressure; this was equal to 0. In case if you have the second type of the rock class category, then recommended support pressure is in the vertical direction varies between 0 to 0.04 Mega Pascal, and the horizontal one is 0. And similarly in the third row corresponds to the third category of the rock mass. In case if you have massive and moderately jointed rock mass so this is how one can find out the vertical support pressure and the horizontal support pressure.

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Modified Terzaghi's theory for tunnels and caverns

Terzaghi's classification			Classification of Singh et al. (1995)				Remarks
Category	Rock condition	Rock load factor, H_p	Category	Rock condition	Recommended support pressure, MPa		
					p_v	p_h	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
IV	Moderately blocky seamy & jointed	$0.25B - 0.35$ $(B+H_t)$	IV	Moderately blocky seamy very jointed	0.07-0.1	0-0.2p_v	Inverts may be required
V	Very blocky & seamy, shattered arched	$0.35 - 1.1$ $(B+H_t)$	V	Very blocky & seamy, shattered highly jointed, thin shear zone or fault	0.1-0.2	0-0.5p_v	Inverts may be required, arched roof preferred
VI	Completely crushed but chemically intact	1.1 $(B+H_t)$	VI	Completely crushed but chemically unaltered, thick shear fault/zone	0.2-0.3	0.3-1.0p_v	Inverts essential, arched roof essential

Similarly, here for the fourth category, again it is moderately blocky seamy but very jointed. So, if you see Terzaghi's classification system, this is what is the rock load factor, and accordingly, you can calculate the support pressure using the expression that we discussed in the last class. And in case of the classification as per Singh et al. 1995, the vertical support pressure can be taken between 0.07 MPa to 0.1 Mega Pascal.

And the horizontal support pressure will vary between 0 to 0.2 times P_v that is the vertical support pressure. Coming to the next category, that is the fifth one, where you have very blocky seamy shattered highly jointed, then thin shear zone or fault. So, you see that in this case of the Terzaghi's classification, this thin shear zone or fault was not included, but that is included in Singh et al., and you have the rock load factor value.

And as compared to this, you have the classification of the Singh et al., And then you have P_v as 0.1 to 0.2 Mega Pascal, and for P_h it is 0 to 0.5 times P_v. And in this case, the inverts may be required, and arched roofs they are preferred similarly the explanation for the sixth type of the rock category has been given here. So, in this case, if I take this modified one which was given by Singh et al. So that is the vertical pressure support pressure is varying between 0.2 to 0.3 Mega Pascal, and the horizontal support pressure is 0.3 to 1 P_v that is the vertical support pressure.

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Modified Terzaghi's theory for tunnels and caverns

Terzaghi's classification			Classification of Singh et al. (1995)				Remarks
Category	Rock condition	Rock load factor, H_p	Category	Rock condition	Recommended support pressure, MPa		
					p_v	p_h	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VII	Squeezing rock at moderate depth	1.1 to 2.1 ($B+H_t$)	VII	Squeezing rock condition			
				A. mild squeezing (u_a/a up to 3%)	0.3-0.4	Depends on primary stress values, p_h may exceed p_v	Inverts essential In excavation, flexible support preferred Circular section recommended
				B. moderate squeezing (u_a/a = 3 – 5%)	0.4-0.6	-do-	-do-

Now, if you have the squeezing rock at moderate depth, so this is what I am talking about Terzaghi classification system, so this is the rock load factor this we have discussed in the previous class as well. But when we come to the classification system of Singh et al. So here they did not go for the squeezing rock at moderate depth or great depth instead, they went for mild squeezing, moderate squeezing, and high squeezing.

So, when they say that moderate squeezing, this means that ua upon a. ua is the radial deformation, and a is the radius of the tunnel. So, if this is up to 3%, then in that case, your vertical support pressure will be 0.3 to 0.4 Mega Pascal. And this P_h will depend upon the primary stress value, and then, in this case, P_h may exceed the value of P_v. In this case, inverts they are essential in excavation flexible supports.

They are preferred, and circular section is recommended in case if you have the moderate squeezing, which is identified as ua upon a varying between 3 to 5%, and here you have the vertical support pressure as 0.4 to 0.6 Mega Pascal, and then the similar recommendation has been given for the horizontal support pressure and the remark category.

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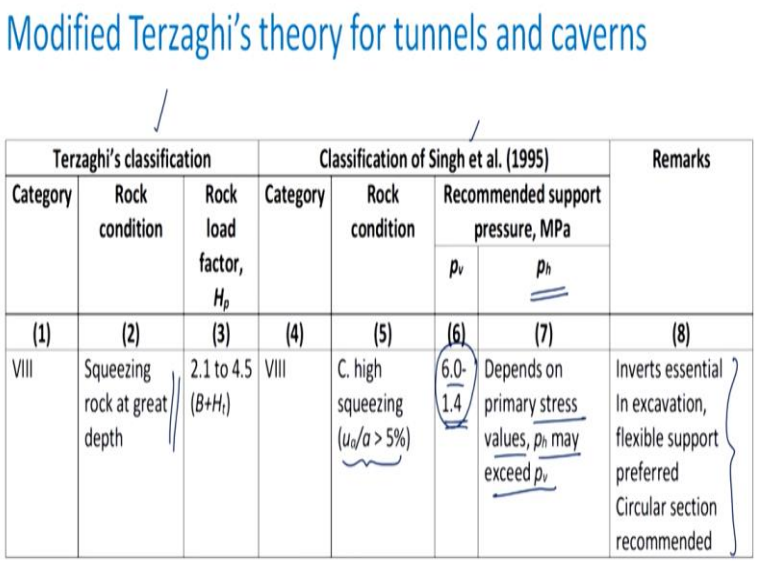

Then, if you have the squeezing rock at great depth, that is as per Terzaghi's classifications system but when you come to the classification system of Singh et al., they have categorized this as high squeezing where ua upon a, is greater than 5%. And in this case, you can see that the vertical pressure is high as compared to the earlier cases, and it is varying from 6 Mega Pascal to 1.4 Mega Pascal it also depends upon the horizontal support pressure depends upon the primary stress values. And in this case, also P_h may exceed P_v and the remarks column again it is the similar one as I discussed with you earlier.

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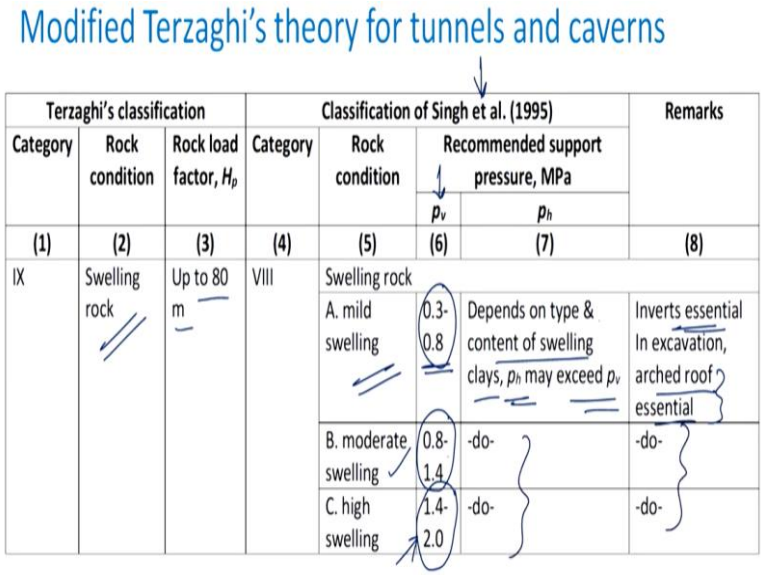

Coming to the last and the final category that is corresponding to swelling rock condition or swelling ground condition. Here the rock load factor, I mentioned to you earlier also it was up to 80 meters, but when it comes to the classification system of this Singh et al., there again it

was divided into mild swelling, moderate swelling, and high swelling category. So, in this case, if you have the mild swelling, the vertical support pressure it varies from 0.3 to 0.8 Mega Pascal.

And the horizontal support pressure it depends upon the type and the content of the swelling clay, and in this case, P_h may exceed P_v. Again, the inverts are essential, and in excavation arched roof, they are essential. Coming to the moderate swelling, so you see as the degree of swelling increases, the support pressure also increases. See, the range here is more as compared to this one for the mild squeezing. And if you go to the high swelling situation again, the range is further high that is 1.4 to 2 mega Pascal and rest all things are same as that was for the mild swelling situation.

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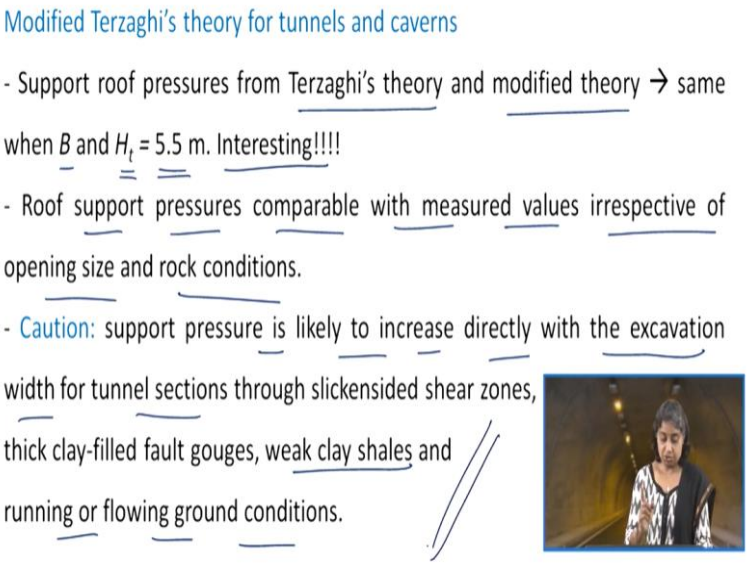

Now there is an interesting observation here that support roof pressure from Terzaghi's theory and the modified theory that we just now saw. It will come out to be same when B and H_t, they are equal to 5.5 meters, so this was an interesting observation. But the roof support pressure they are comparable with the measured values irrespective of opening size and the rock condition when we followed this modified Terzaghi's theory.

But the caution is that the support pressure is likely to increase directly with the excavation width for tunnel sections. Especially through slicken-sided shear zones or thick clay-filled fault gouges, weak clay shales, and running or flowing ground conditions. So, these ground conditions I have already explained you, so maybe you can connect that why we took ground conditions discussion much earlier so some of these things one needs to keep in mind.

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Modified Terzaghi's theory for tunnels and caverns

- Under these conditions, interlocking of blocks is likely to be missing or where joint strength is lost and rock wedges are allowed to fall due to excessive roof convergence on account of delayed supports beyond stand-up time.
- Wider tunnels shall require reduced spacing of bolts or steel arches and thicker linings since rock loads increase directly with the excavation width even if the support pressure does not increase with the tunnel size.

Now, if such conditions are there so in that case what happens is that interlocking of the blocks is kind of missing or where the joint strength is lost, and the rock wedges are allowed to fall due to excessive roof convergence on account of the delayed supports beyond the stand-up time. So, the wider tunnels shall require reduced spacing of bolts in such cases or steel arches and may be thicker linings.

Since, in that case, the rock loads increase directly with the excavation width even if the support pressure does not increase with the tunnel size so this was all about the Terzaghi's theory and its application to the analysis and design of the underground excavations. In the next class, we will take up another classification system which is a rock mass rating, and then we will see that what all can be the applications of rock mass rating with reference to the design of underground excavations. Thank you very much.