Underground Space Technology
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Module No # 07
Lecture No # 35
Tunnel Hazards: Squeezing ground Conditions

Hello everyone, in the previous class, we discussed some aspects related to tunnel hazards. This was in continuation with the application of various rock mass classification systems. So, today we will continue the same discussion with reference to tunnel hazards and specific mention of the squeezing ground conditions, and then we will see how the application of the Q-system can be made in the underground space technology or the design of underground excavations.

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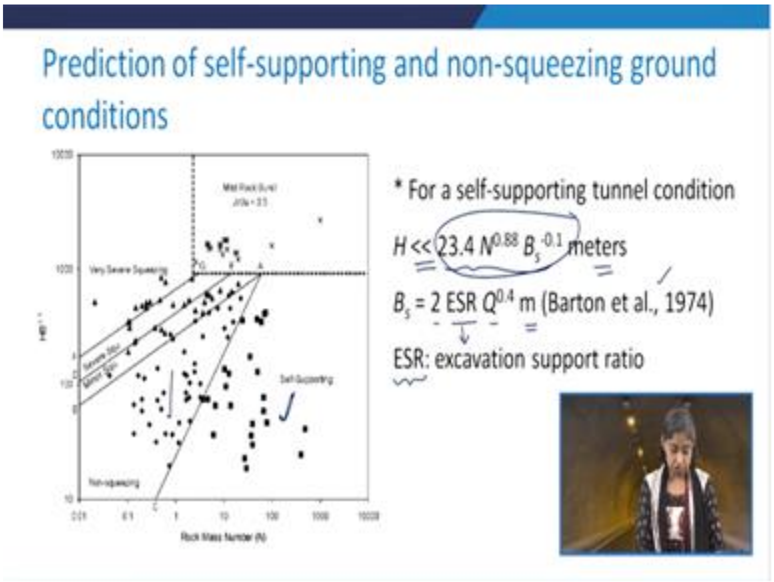

Prediction of self-supporting and non-squeezing ground conditions

* For a self-supporting tunnel condition

$H << 23.4\, N^{0.88}\, B_s^{-0.1}$ meters

$B_s = 2\, ESR\, Q^{0.4}$ m (Barton et al., 1974)

ESR: excavation support ratio

So, this figure we discussed in the previous class, and we saw how this line BA was clearly identifying the two areas, one being the non-squeezing and another being the squeezing ground condition. So, we continue with this, and we try to see some other types of the ground conditions, such as self-supporting and non-squeezing. And also, in the squeezing ground conditions, it has further been classified as minor squeezing, severe squeezing, and very severe squeezing.

So, let us have a discussion about these today. So, Goyal et al. 1995, they proposed an additional criterion to estimate the self-supporting ground condition. Here, in this figure, you take a look at the line CA, which is this one. So, this is clearly demarcating the area which is self-supporting and which is not. So, if we are in this zone towards the right-hand side of this line, then we are in the self-supporting zone.

But, if we go towards the other side, it is the non-squeezing ground condition, which is not self-supporting. That means although it is going to be the non-squeezing ground condition. But some support system would be required, and the equation of this line CA is given by:

$$H = 23.4N^{0.88}{B_s}^{-0.1}$$

The units are in meters. We need to be careful about the units because all these are empirical correlations.

I have been emphasizing this again and again throughout this course. Now here, this N is the rock mass number that we discussed when we discussed about the Q system, and this B_s here is the unsupported span length in meters. Now, for a self-supporting tunnel condition, this H has to be much less than this expression which is:

$$H \ll 23.4N^{0.88}{B_s}^{-0.1}$$

B_s as I mentioned that it is an unsupported span which can also be defined as:

$$B_s = 2\ ESR\ Q^{0.4}\ m$$

This is as per Barton et al. in 1974, where this ESR, is the excavation support ratio. We will see, a little later, how to assign the values to this ESR. So, you see that in case the depth of overburden is much less than this expression. We will be in this zone that is self-supporting, and if not, then we come to the other portion of this line CA.

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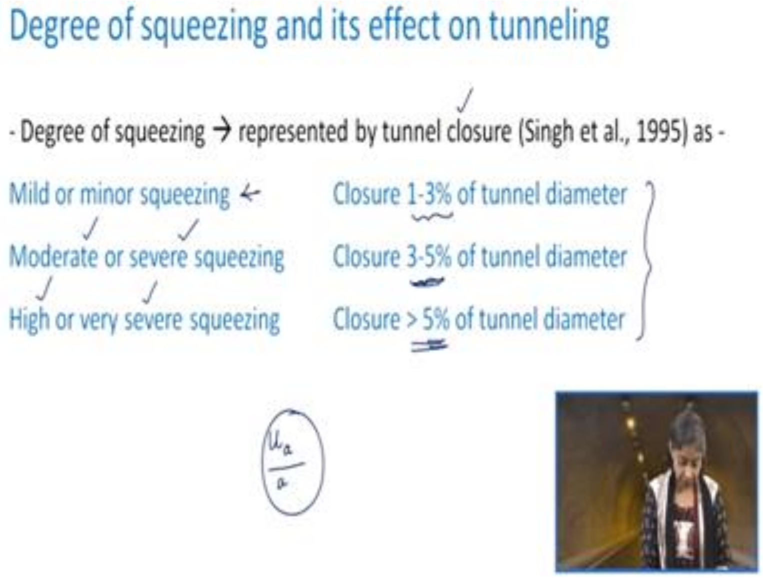

Degree of squeezing and its effect on tunneling

- Degree of squeezing → represented by tunnel closure (Singh et al., 1995) as -

Mild or minor squeezing ←	Closure 1-3% of tunnel diameter
Moderate or severe squeezing	Closure 3-5% of tunnel diameter
High or very severe squeezing	Closure > 5% of tunnel diameter

$\frac{u_a}{a}$

Now, coming to the prediction of the degree of squeezing so, what we have done already, is that we have identified the situations such as squeezing ground condition, non-squeezing ground condition, and self-supporting ground condition. Coming to the squeezing ground condition, depending upon what is tunnel closure taking place, we can identify various degrees of squeezing, and we will also learn about its effect on tunneling.

Plus, we will also have to look into the aspect related to rock burst. So, first, let us focus on the degree of squeezing and its effect on tunneling. So, this is represented by the tunnel closure, as I mentioned. So, in case you have mild or minor squeezing, this is represented by the fact when the tunnel closure is of the order of 1 to 3 % of the tunnel diameter. So, let us say that tunnel closure, if I nominate with the u_a, this divided by the say, this is the tunnel diameter a.

Then if this is of the order of 1 to 3%, then we can call this mild or minor squeezing. Then the second category belongs to the moderate or severe squeezing; in that case, you can see that the closure is more. Here it is to the tune of 3 to 5% of the tunnel diameter, and that again, we are calling as moderate or severe squeezing. In case, if this closure is more, furthermore then that falls under the category of high or very severe squeezing.

In this case, we are defining the closure to be more than 5% of the tunnel diameter. So, you should keep these limits in mind to decide the degree of squeezing, whether it is mild squeezing, moderate squeezing, or high or very severe squeezing.

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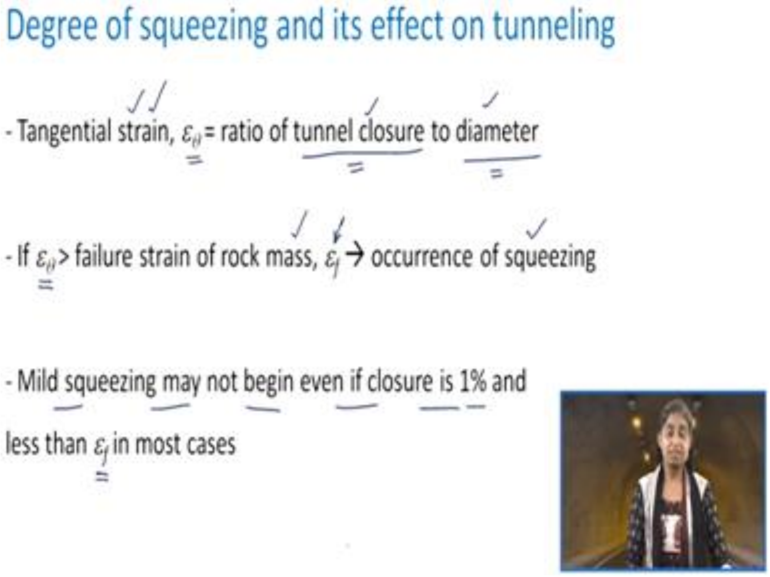

Degree of squeezing and its effect on tunneling

- Tangential strain, ε_θ = ratio of tunnel closure to diameter
- If ε_θ > failure strain of rock mass, ε_f → occurrence of squeezing
- Mild squeezing may not begin even if closure is 1% and less than ε_f in most cases

Coming to its effect, so first let us focus on some of the aspects related to strains that are going to be developed. So, the tangential strain is represented by ε_θ. It is the ratio of tunnel closure to the diameter. So, you see that the strain will not have any dimensions. So, when we say that the ratio of tunnel closure to diameter means both of these have the unit of length, and hence the strain will be the dimensionless quantity.

Now, if this strain is more than the failure strain of the rock mass, which is represented by ε_f, there is going to be the occurrence of squeezing. Now, the mild squeezing may not begin even if the closure is 1%, and it is less than ε_f in most of the cases.

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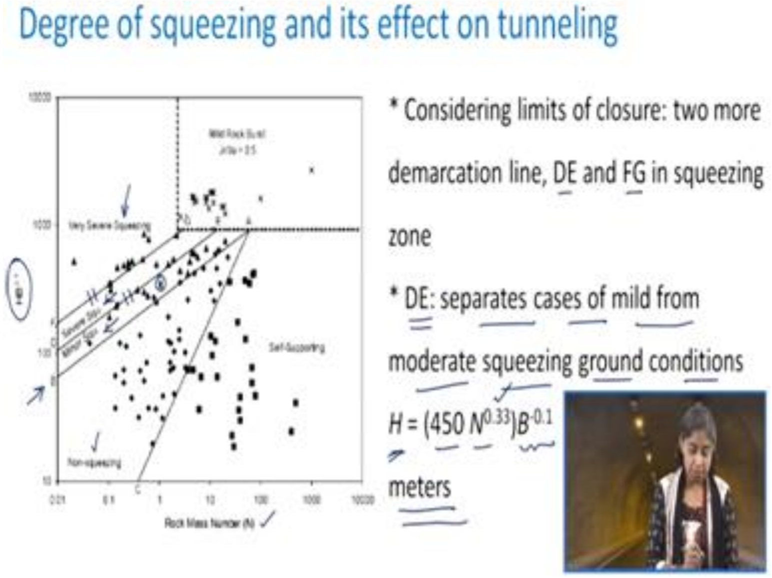

Degree of squeezing and its effect on tunneling

* Considering limits of closure: two more demarcation line, DE and FG in squeezing zone

* DE: separates cases of mild from moderate squeezing ground conditions

$H = (450\, N^{0.33}) B^{-0.1}$ meters

Now, if we consider these limits of closure, we can further classify or demarcate the squeezing zone with the help of the two lines DE and FG. So, you see that this is what is DE, and this is FG. So, basically this line BA was the line that was differentiating between non-squeezing and squeezing ground conditions. Now further, with the help of the lines DE and FG, we are going to further classify this squeezing zone into three zones.

One is minor squeezing, severe squeezing, and very severe squeezing. So, focus on this line DE. This separates cases of mild squeezing from the moderate squeezing ground conditions and is represented by the equation:

$$H = (450N^{0.33})B^{-0.1}$$

The units of H are going to be in meters. So, if let us say if we plot rock mass number N versus H into B to the power of 0.1 and if the point lies between the line BA and DE that means here, then this will be called as minor squeezing.

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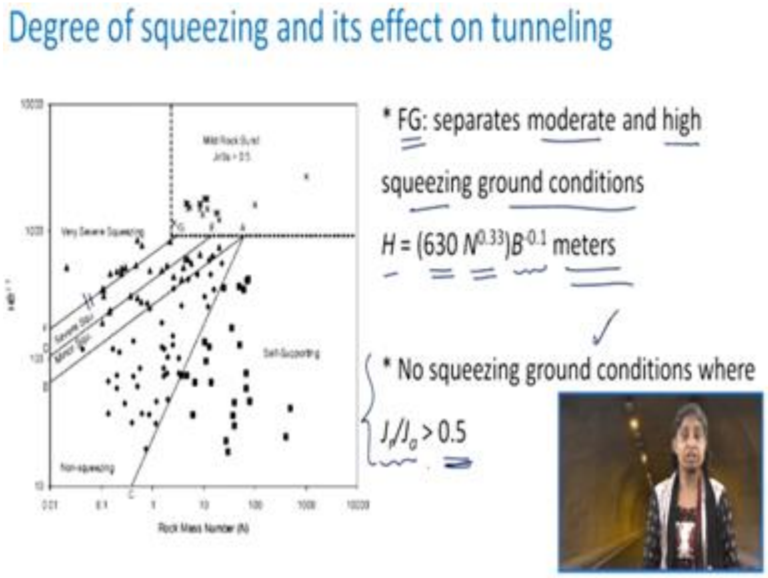

Degree of squeezing and its effect on tunneling

* FG: separates moderate and high squeezing ground conditions

$H = (630\ N^{0.33})B^{-0.1}$ meters

* No squeezing ground conditions where $J_r/J_a > 0.5$

Coming to the further separation that is focused on line FG. Now, this separates moderate and high squeezing ground conditions and is represented by the equation:

$$H = (630N^{0.33})B^{-0.1}$$

Now, in the case of the parameter J_r upon J_a more than 0.5, there are not going to be any squeezing ground conditions. When there are squeezing grounds conditions J_r upon J_a will be more than 0.5. So now, what happens when J_r upon J_a is more than 0.5? We will see this?

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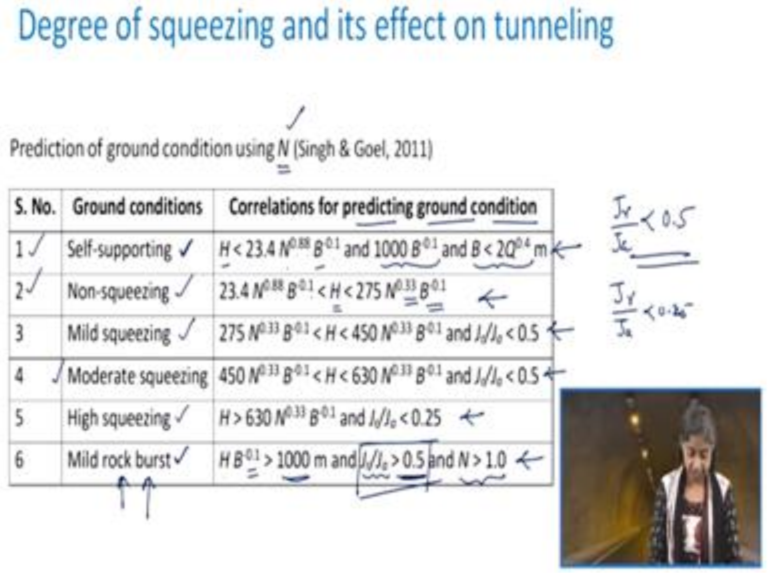

Degree of squeezing and its effect on tunneling

Prediction of ground condition using N (Singh & Goel, 2011)

S. No.	Ground conditions	Correlations for predicting ground condition
1	Self-supporting	$H < 23.4\ N^{0.88}\ B^{-0.1}$ and $1000\ B^{-0.1}$ and $B < 2Q^{0.4}$ m
2	Non-squeezing	$23.4\ N^{0.88}\ B^{-0.1} < H < 275\ N^{0.33}\ B^{-0.1}$
3	Mild squeezing	$275\ N^{0.33}\ B^{-0.1} < H < 450\ N^{0.33}\ B^{-0.1}$ and $J_r/J_a < 0.5$
4	Moderate squeezing	$450\ N^{0.33}\ B^{-0.1} < H < 630\ N^{0.33}\ B^{-0.1}$ and $J_r/J_a < 0.5$
5	High squeezing	$H > 630\ N^{0.33}\ B^{-0.1}$ and $J_r/J_a < 0.25$
6	Mild rock burst	$H\ B^{-0.1} > 1000$ m and $J_r/J_a > 0.5$ and $N > 1.0$

$\frac{J_r}{J_a} < 0.5$

$\frac{J_r}{J_a} < 0.25$

We will come to that condition a little later when J_r upon J_a is more than 0.5 but then based upon the discussion that we had in continuation to the previous class. Here we have identified the various ground conditions using this rock mass number N, and these have been tabulated here. So, at serial number 1, you have the self-supporting ground conditions and the correlations which are applicable for the prediction of the ground condition.

That is self-supporting. It will be these expressions. That means H should be:

$$H < 23.4N^{0.88}{B_s}^{-0.1}\ and\ 1000{B_s}^{-0.1}\ and\ B < 2\ Q^{0.4}\ m$$

So, for the ground condition to be self-supporting, each of these 3 conditions should be satisfied.

Coming to the second category, which is the non-squeezing ground condition, for this, the correlation is this second row which is that the depth of overburden should be between these 2 expressions, which are:

$$23.4N^{0.88}{B_s}^{-0.1} < H < 275N^{0.33}{B_s}^{-0.1}$$

And then, in the similar manner, the mild squeezing, moderate squeezing, and high squeezing ground conditions can also be predicted following these correlations.

Keep that in mind that here J_r upon J_a, they are less than 0.5 in case of mild squeezing and moderate squeezing, and when we come to the high squeezing, it is even less than 0.25. Now, the next category for the ground condition is the rock bust, and as per the prediction of the ground condition using N, we are calling this a mild rock bust and these are the conditions or correlations that should be satisfied then; only you can say that ok.

Here, it is a probability that a mild rock burst may occur. So, what are those conditions?

$$H{B_s}^{-0.1}\ > 1000\ m\ and\ J_r/J_a > 0.5\ and\ N > 1.0$$

So, take note here that when J_r upon J_a is more than 0.5. It is no more the squeezing ground condition but the mild rock burst condition, and in this case, rock mass number N is greater than 1.

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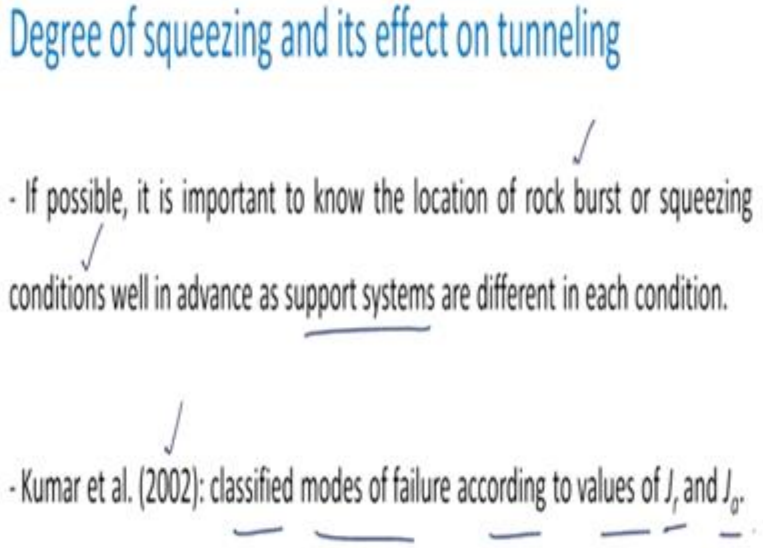

Degree of squeezing and its effect on tunneling

- If possible, it is important to know the location of rock burst or squeezing conditions well in advance as support systems are different in each condition.

- Kumar et al. (2002): classified modes of failure according to values of J_r and J_a.

Now, if it is possible, it will be important to know the location of rock burst or squeezing conditions, well in advance. The reason is that the support systems for both of these ground conditions are going to be different in all the locations. So let us say that at one location, it is the rock bust that is expected in another location. If it is the squeezing ground condition in both situations, the support systems are going to be altogether different.

So, it is extremely important for us to know the location of these rock busts or squeezing conditions. Or to say in a more general manner, it is important for us to predict the ground condition a priory. Because then only we will be able to do the analysis and design in a proper manner with the proper design of the support systems as well. Now, Kumar et al. 2002, they classified modes of failure according to the values of J_r and J_a.

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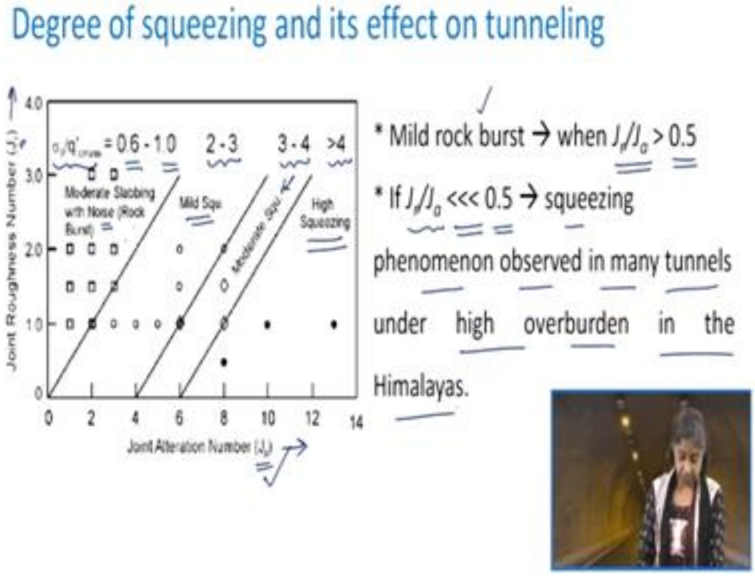

Degree of squeezing and its effect on tunneling

- Mild rock burst → when $J_r/J_a > 0.5$
- If $J_r/J_a <<< 0.5$ → squeezing phenomenon observed in many tunnels under high overburden in the Himalayas.

So, this was the figure that was proposed by them on the x-axis. You can see that you have the joint alteration number J_a and, on the y-axis, you have the joint roughness number J_r. So based on that, they superimposed some of the experimental data, and they divided this whole area into four zones. So, the first zone was corresponding to moderate slabbing with noise this means that this is corresponding to rock burst. And you see that in this case, σ_θ upon $\sigma'_{c\ mass}$ is very high, and it is varying between points 6 and 1.

In case, if this is between 2 and 3, it is the mild squeezing that is expected. If it is 3 to 4, it is the moderate squeezing. If it is greater than 4, then it is high squeezing which is expected. So, take a note again here that mild rock burst is associated with the condition when J_r upon J_a is greater than 0.5. Now, if J_r upon J_a, they are much less than 0.5, the squeezing phenomenon is observed in many tunnels under high overburden in the Himalayan region.

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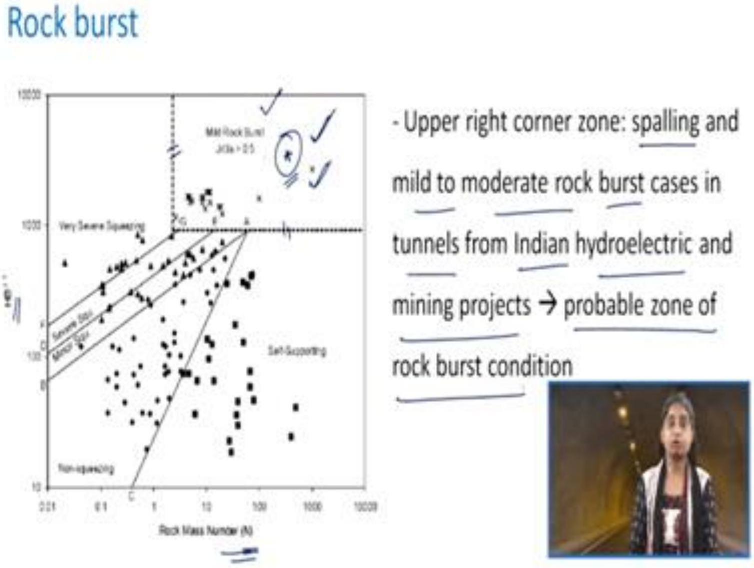

Rock burst

- Upper right corner zone: spalling and mild to moderate rock burst cases in tunnels from Indian hydroelectric and mining projects → probable zone of rock burst condition

Focus on the rock burst condition because we discussed what is the degree of squeezing? Various degrees of squeezing are based upon the tunnel closure. Now, we focus on the rock burst. So, take a look here at the upper right corner zone, which is shown by this dotted rectangle. This is what is the mild rock burst zone? Here, in this case, if the point corresponding to rock mass number and H into B to the power of 0.1 falls in this zone.

Then what happens is that spalling and mild to moderate rock burst takes place here in this zone, and these conditions were observed when there were many case studies which were taken related to tunnels from Indian hydroelectric and mining projects. So, basically, what was done is that based upon these experiences, all these data points were mapped onto this space which is HB to the power 0.1 versus the rock mass number N.

And if the point lies in this zone, then it is called that here there is going to be the occurrence of rock bust or the ground condition is called as the mild rock bust. So, this is what is going to be the probable zone of rock burst condition.

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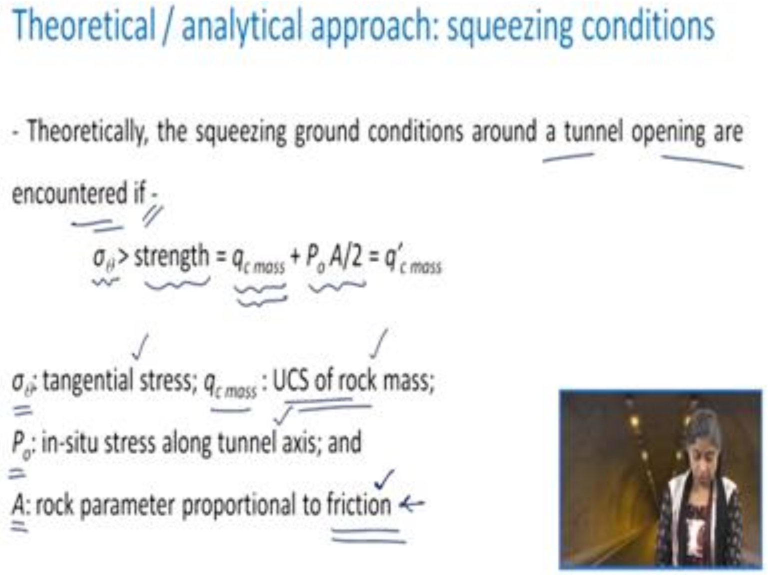

Theoretical / analytical approach: squeezing conditions

- Theoretically, the squeezing ground conditions around a tunnel opening are encountered if -

σ_θ > strength = $q_{c\,mass} + P_o A/2 = q'_{c\,mass}$

σ_θ: tangential stress; $q_{c\,mass}$: UCS of rock mass;
P_o: in-situ stress along tunnel axis; and
A: rock parameter proportional to friction

Now, how can we define or identify whether it is going to be the squeezing condition as far as the theoretical or analytical approaches are concerned? Till now, what we saw was the empirical approaches. So, let us take a look here now that theoretically, the squeezing ground conditions around the tunnel opening, they are encountered if this σ_θ is more than this strength which is defined as the:

$$\sigma_\theta > strength = q_{c\,mass} + \frac{P_o\,A}{2} = q_{c\,mass}{}'$$

So, where the σ_θ is the tangential stress, $q_{c\ mass}$ is the UCS of the rock mass, P_o is the in-situ stress along the tunnel axis, and A be the rock parameter that is proportional to friction. So, you see that this is quite similar to the criteria which were there for more coulomb relationships. So, this A is the parameter connecting to the friction angle, and $q_{c\ mass}$ is the cohesion, kind of representing the cohesive component, but then it is UCS of the rock mass.

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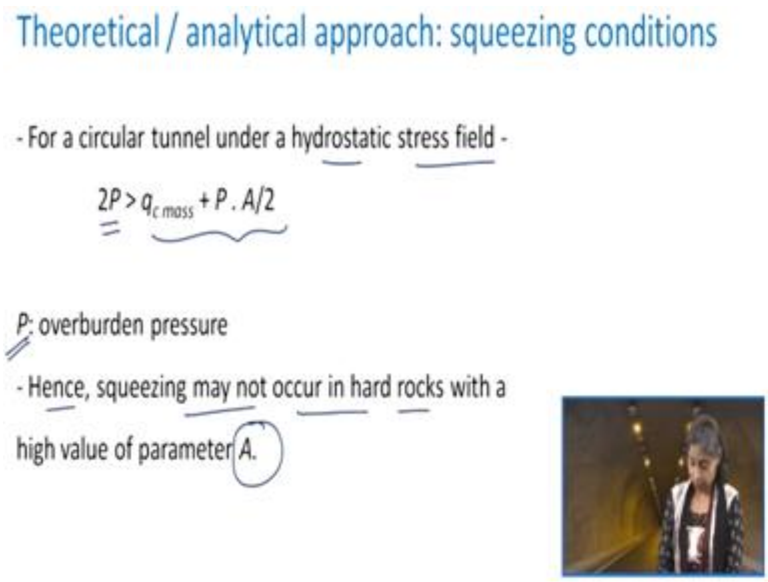

Theoretical / analytical approach: squeezing conditions

- For a circular tunnel under a hydrostatic stress field -

$2P > q_{c\,mass} + P.A/2$

P: overburden pressure

- Hence, squeezing may not occur in hard rocks with a high value of parameter A.

So, if we take a particular case of a hydrostatic stress field, in that case, and if it is for a circular tunnel so, in that case, this 2P should be:

$$2P > q_{c\,mass} + \frac{PA}{2}$$

Where this P will be now overburdened pressure and therefore squeezing may not occur in the hard rock when it has a very high value of this parameter A, which is directly related to the frictional component.

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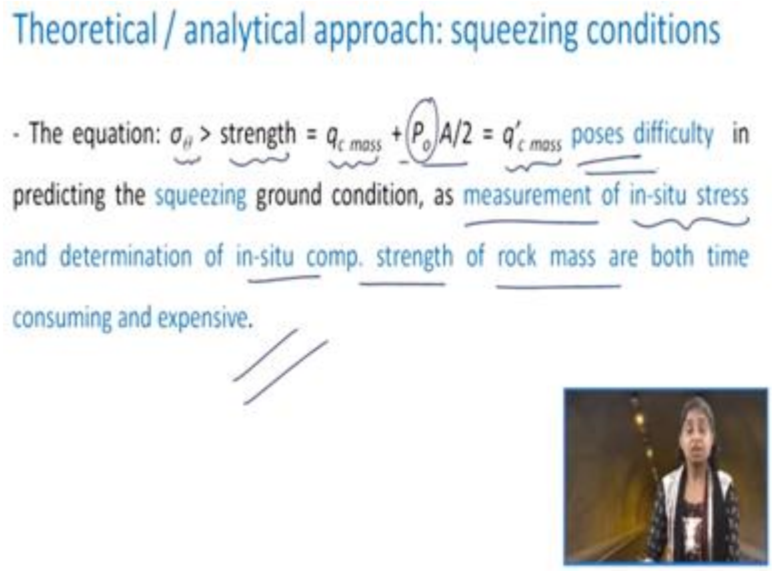

Theoretical / analytical approach: squeezing conditions

- The equation: $\sigma_\theta >$ strength $= q_{c\,mass} + P_o A/2 = q'_{c\,mass}$ poses difficulty in predicting the squeezing ground condition, as measurement of in-situ stress and determination of in-situ comp. strength of rock mass are both time consuming and expensive.

The equation which is sigma theta if it is more than strength which is:

$$\sigma_\theta > strength = q_{c\,mass} + \frac{P_o\,A}{2} = q_{c\,mass}'$$

It poses difficulty in the prediction of squeezing ground condition, the reason being that here this P_o be the in-situ state of stress, and it is not that simple to have the idea about this in the field. Because the measurement of this in-situ compressive strength of the rock mass these are both time-consuming as well as expensive.

With due course of time in this subject only, we will learn about various methods which are adopted for the in-situ determination of the strength of the rock mass. So, as of now, just remember that these are not that simple test to be conducted in the field, and therefore this equation we will find it difficult to use.

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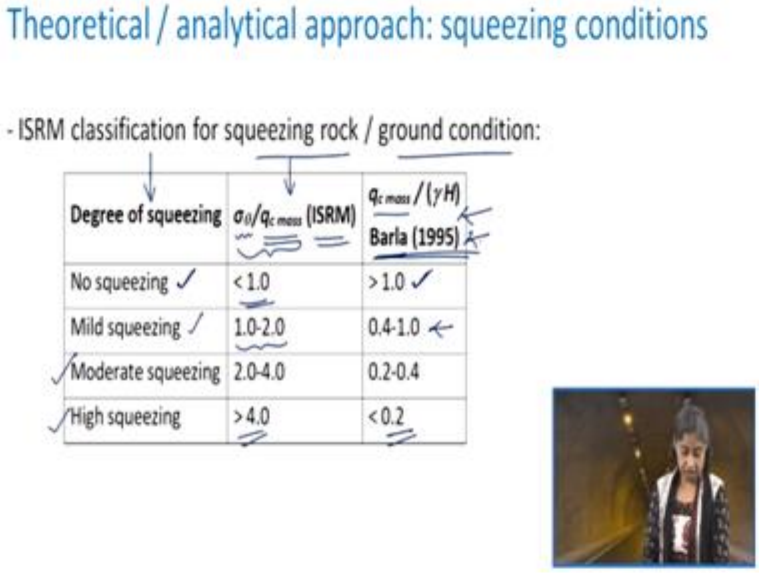

Theoretical / analytical approach: squeezing conditions

- ISRM classification for squeezing rock / ground condition:

Degree of squeezing	$\sigma_\theta/q_{c\,mass}$ (ISRM)	$q_{c\,mass}/(\gamma H)$ Barla (1995)
No squeezing ✓	< 1.0	> 1.0 ✓
Mild squeezing ✓	1.0-2.0	0.4-1.0
✓ Moderate squeezing	2.0-4.0	0.2-0.4
✓ High squeezing	> 4.0	< 0.2

So, here this ISRM classification can be used for squeezing rock or the ground condition. So, we have the degree of squeezing here, and then the second column corresponds to σ_θ by $q_{c\ mass}$, and then that last one is $q_{c\ mass}$ divided by γ into H. This was given by Barla in 1995. So, in this case, if it is the no-squeezing ground condition. So, this quantity will be less than 1, but as per Barla, this $q_{c\ mass}$ by γ H will be greater than 1.

In the case of mild squeezing, the variation of sigma theta by $q_{c\ mass}$ as per ISRM standards is 1 to 2. But in reference to Barla, the $q_{c\ mass}$ by γ H is .421. Similarly, we have the ranges for moderate squeezing and for high squeezing, we have as per ISRM standard. It is σ_θ upon $q_{c\ mass}$ should be greater than 4 for high squeezing ground condition, and $q_{c\ mass}$ by γ H should be less than 0.2. For the high squeezing ground condition as per Barla, which was given in 1995.

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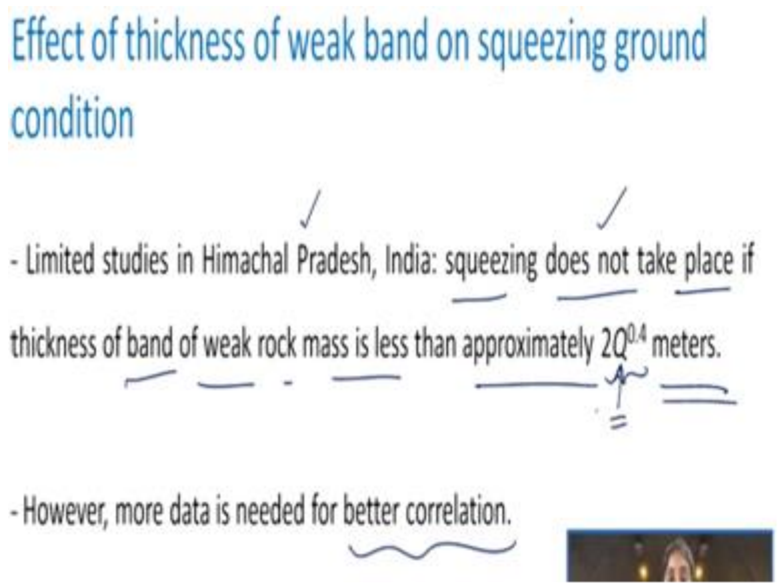

Effect of thickness of weak band on squeezing ground condition

- Limited studies in Himachal Pradesh, India: squeezing does not take place if thickness of band of weak rock mass is less than approximately $2Q^{0.4}$ meters.

- However, more data is needed for better correlation.

Now, the effect of the thickness of the weak band on the squeezing ground condition is quite significant. Although very few studies have been conducted, especially in the area of Himachal Pradesh, India. So, based upon some of the outcomes which appeared there the squeezing do not take place if the thickness of the band of weak rock mass is less than approximately 2 cubes to the power 0.4 meters.

So, what is Q here? it is the rock mass quality index Q so we can find out 2 Q to the power 0.4 and if the thickness of the band of weak rock mass is less than these. Then we can say that squeezing will not take place. But, then again, the source of this information is the limited studies that were conducted in a particular zone in India. So, if you want to generalize it, we need to have more data to have the better correlation.

So, this was all about the tunnel hazard, especially with reference to the squeezing ground conditions. In the next class, we will learn about the various applications of rock mass classification systems which we are going to take up as the Q-system. Thank you very much.