Rock Mechanics and Tunneling
Professor Dr. Debarghya Chakraborty
Department of Civil Engineering
Indian Institute of Technology, Kharagpur
Lecture 25
Rock mass classification (Continued)

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Hello, everyone. I welcome all of you to the fourth lecture of module 05. So, in module 05, we are discussing about the rock mass classification. So, we will continue with that only.

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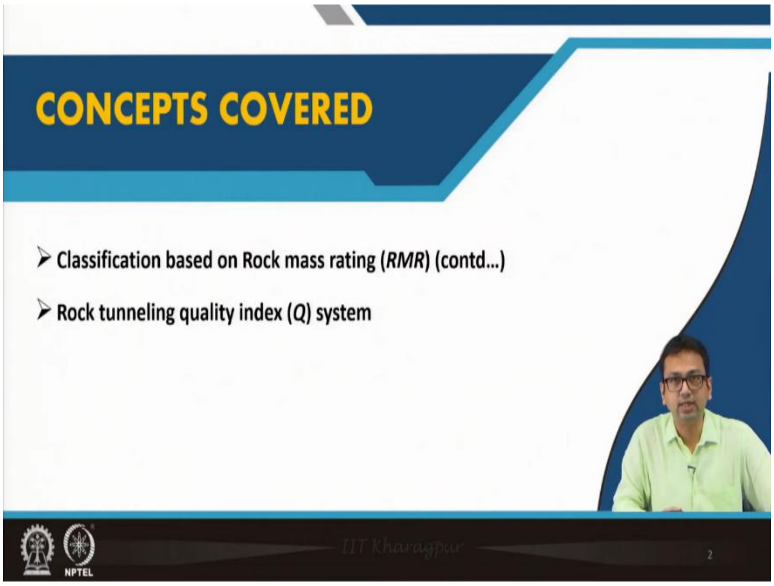

Today, I will take another problem on RMR system to make our understanding even better. Later, we will also discuss about the rock tunnelling quality index, that is Q system.

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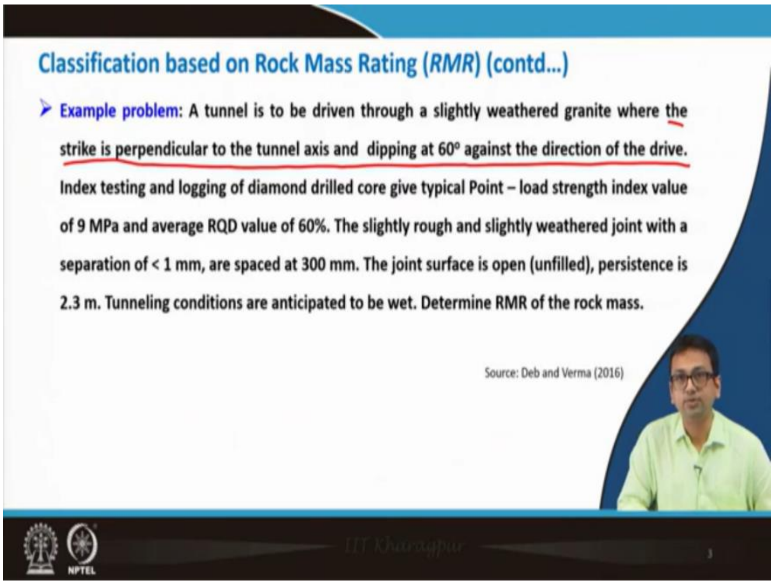

Example problem: A tunnel is to be driven through a slightly weathered granite where the strike is perpendicular to the tunnel axis and dipping at 60 degrees against the direction of the drive. Index testing and logging of diamond drilled core give typical point load strength index value of 9 MPa and average RQD value of 60 %. The slightly rough and slightly weathered joint with a separation of < 1 mm are spaced at 300 mm. The joint surface is open (unfilled), persistence is 2.3 m, tunnelling conditions are anticipated to be wet. Determine the RMR of the rock mass.

Solution:

As per RMR table 3, for the condition where the strike is perpendicular to the tunnel axis and tunnel is to be driven against the dip and also dipping at 60 degrees the description is **'Fair'**.

Now, using RMR table 4, the adjustment of rating is **-5**.

As per RMR table 1, for the condition of discontinuities, the rating is **25** (slightly rough, slightly weathered and separation < 1 mm).

Since, we have detailed information about the condition of discontinuities we should use RMR table 2.

Prepare a table as we have done in the previous example

Classification parameters	Description	According to RMR table	Rating
Strength of intact rock materials(UCS)	9 MPa	1	12
RQD	60%	1	13
Spacing of discontinuities	0.3 m	1	10
Discontinuity Length (Persistence)	2.3 m	2	4
Separation or aperture	<1mm		4
Infilling (gouge)	None		6
Roughness	Slightly rough		3
Weathering	Slightly weathered		5
Ground water	Wet	1	7
Adjustment for discontinuity orientation	Fair, Tunnel	3,4	-5
		Total RMR value	59

Therefore, the rock can be considered as **Fair rock** [as per RMR table 5] (Ans)

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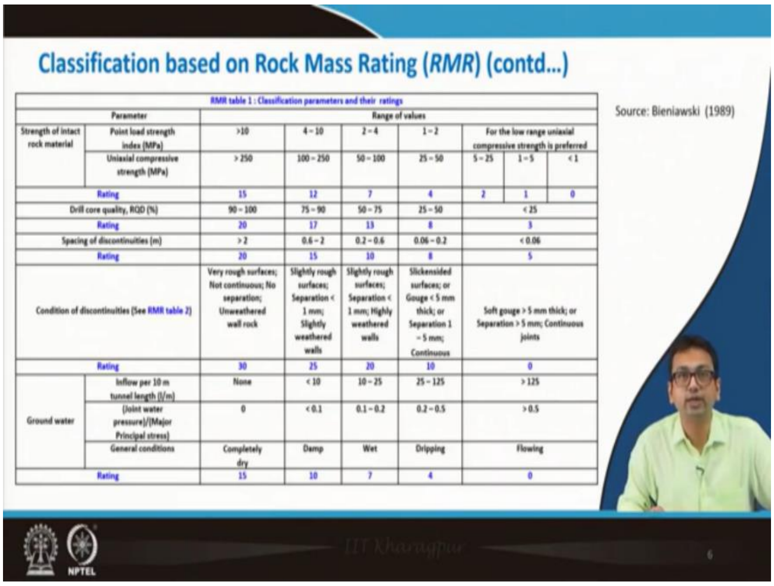

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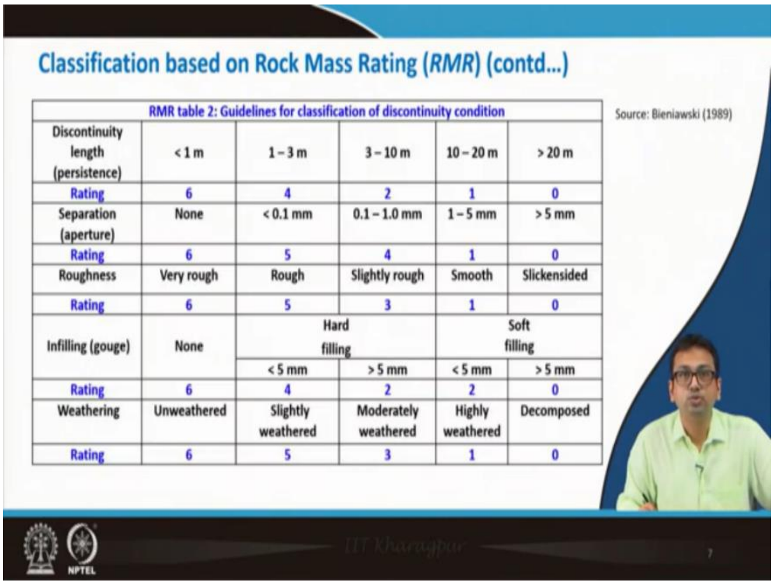

Table 2.

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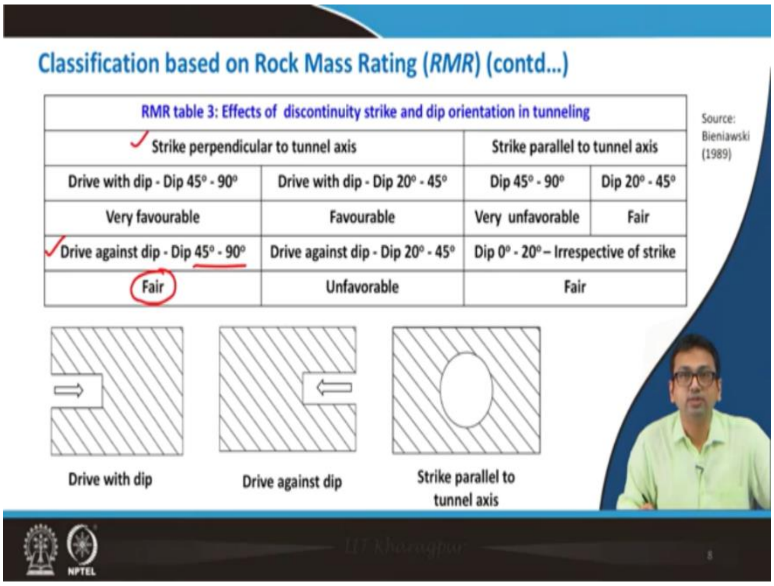
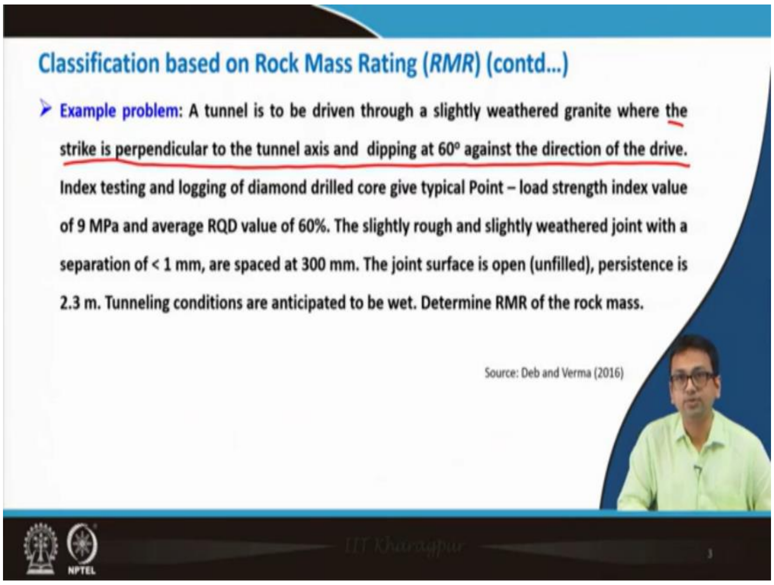


Classification based on Rock Mass Rating (*RMR*) (contd...)

RMR table 3: Effects of discontinuity strike and dip orientation in tunneling			
Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip - Dip 45° - 90°	Drive with dip - Dip 20° - 45°	Dip 45° - 90°	Dip 20° - 45°
Very favourable	Favourable	Very unfavorable	Fair
Drive against dip - Dip 45° - 90°	Drive against dip - Dip 20° - 45°	Dip 0° - 20° – Irrespective of strike	
Fair	Unfavorable	Fair	



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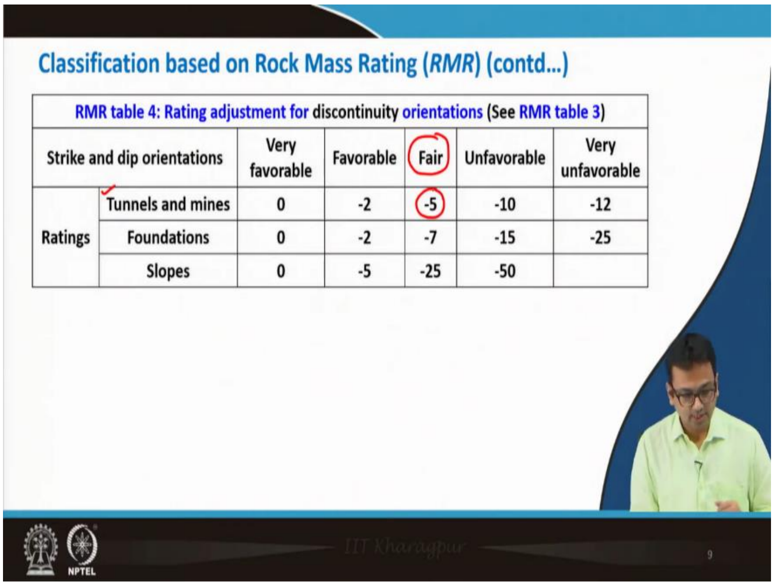

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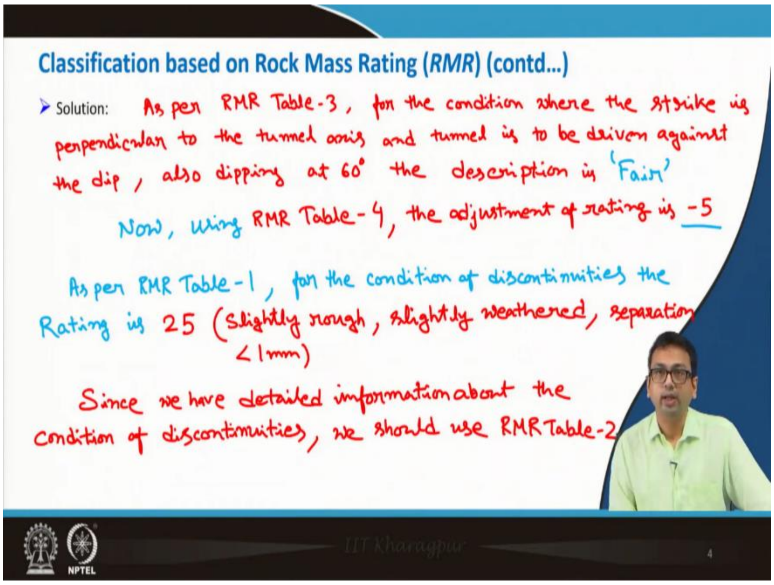
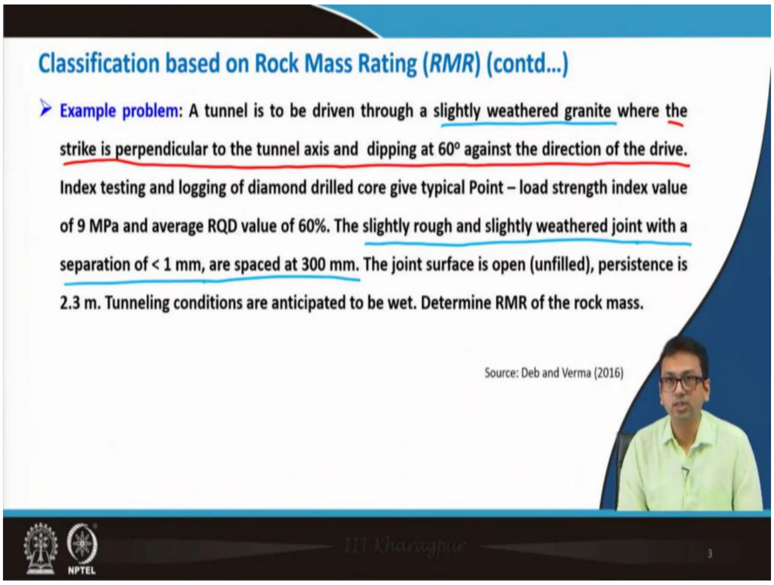
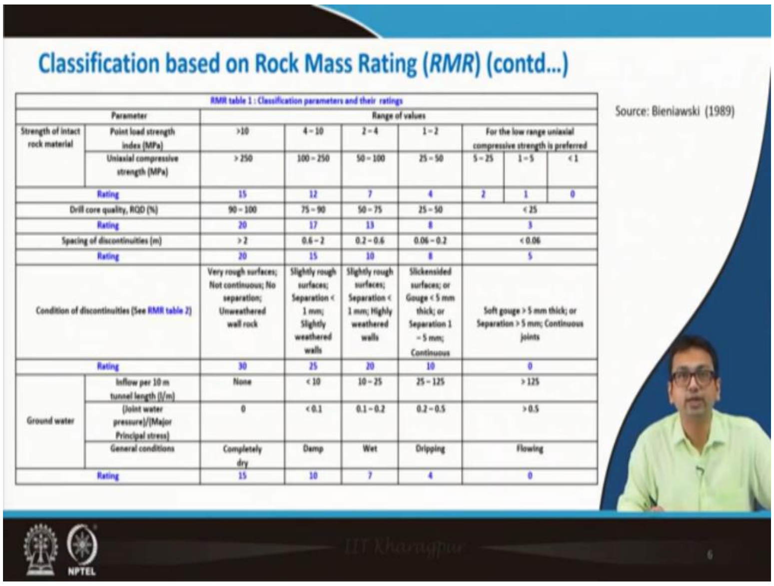
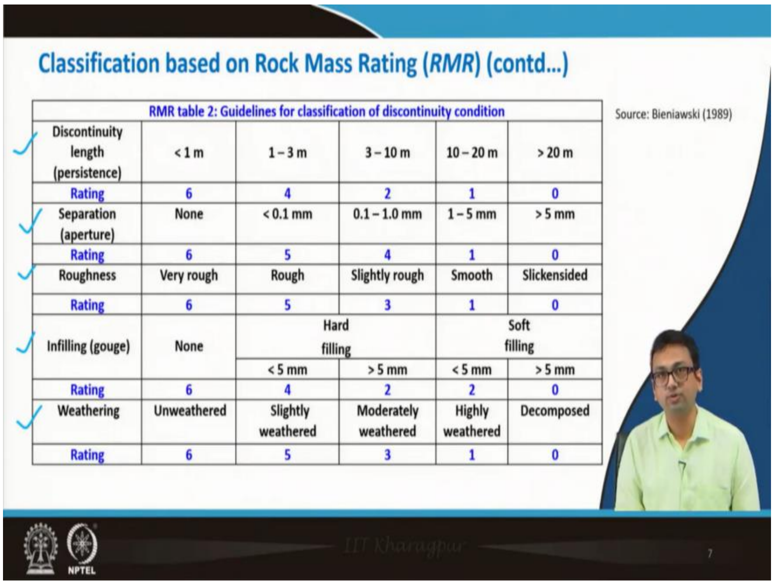






RMR table 1 : Classification parameters and their ratings

Parameter		Range of values						
Strength of intact rock material	Point load strength index (MPa)	>10	4 – 10	2 – 4	1 – 2	For the low range uniaxial compressive strength is preferred		
	Uniaxial compressive strength (MPa)	> 250	100 – 250	50 – 100	25 – 50	5 – 25	1 – 5	< 1
Rating		15	12	7	4	2	1	0
Drill core quality, RQD (%)		90 – 100	75 – 90	50 – 75	25 – 50	< 25		
Rating		20	17	13	8	3		
Spacing of discontinuities (m)		> 2	0.6 – 2	0.2 – 0.6	0.06 – 0.2	< 0.06		
Rating		20	15	10	8	5		
Condition of discontinuities (See RMR table 2)		Very rough surfaces; Not continuous; No separation; Unweathered wall rock	Slightly rough surfaces; Separation < 1 mm; Slightly weathered walls	Slightly rough surfaces; Separation < 1 mm; Highly weathered walls	Slickensided surfaces; or Gouge < 5 mm thick; or Separation 1 – 5 mm; Continuous	Soft gouge > 5 mm thick; or Separation > 5 mm; Continuous joints		
Rating		30	25	20	10	0		
Ground water	Inflow per 10 m tunnel length (l/m)	None	< 10	10 – 25	25 – 125	> 125		
	(Joint water pressure)/(Major Principal stress)	0	< 0.1	0.1 – 0.2	0.2 – 0.5	> 0.5		
	General conditions	Completely dry	Damp	Wet	Dripping	Flowing		
Rating		15	10	7	4	0		



RMR table 2: Guidelines for classification of discontinuity condition

Discontinuity length (persistence)	< 1 m	1 – 3 m	3 – 10 m	10 – 20 m	> 20 m
Rating	6	4	2	1	0
Separation (aperture)	None	< 0.1 mm	0.1 – 1.0 mm	1 – 5 mm	> 5 mm
Rating	6	5	4	1	0
Roughness	Very rough	Rough	Slightly rough	Smooth	Slickensided
Rating	6	5	3	1	0
Infilling (gouge)	None	Hard filling		Soft filling	
		< 5 mm	> 5 mm	< 5 mm	> 5 mm
Rating	6	4	2	2	0
Weathering	Unweathered	Slightly weathered	Moderately weathered	Highly weathered	Decomposed
Rating	6	5	3	1	0

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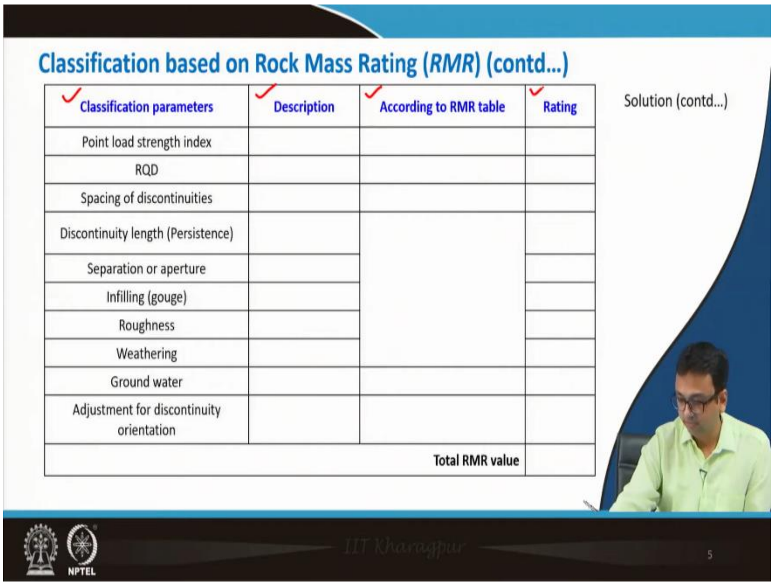

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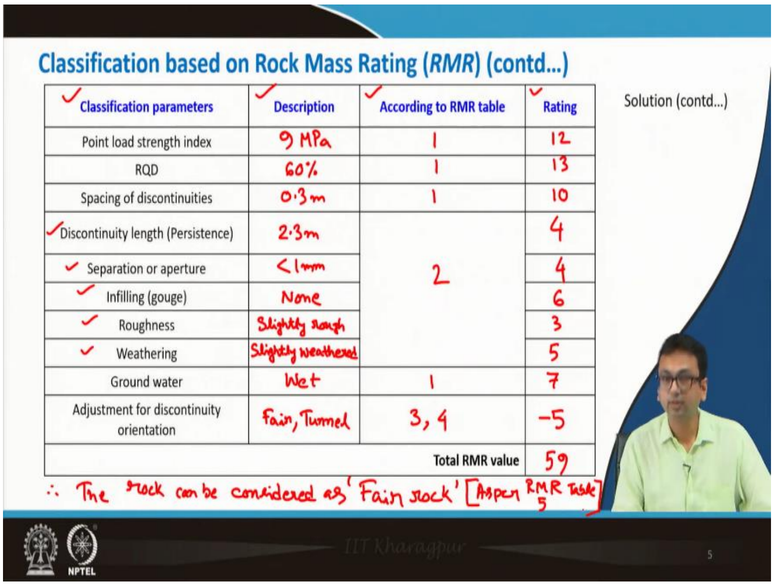
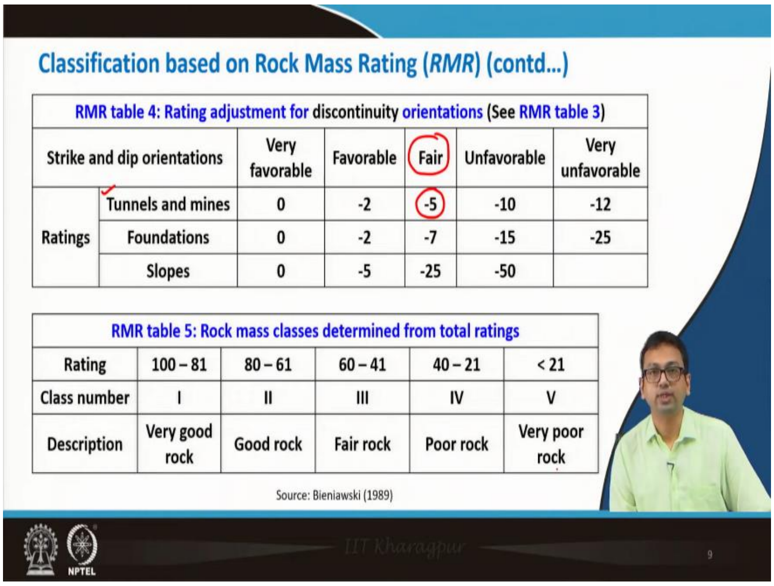




Classification based on Rock Mass Rating (*RMR*) (contd...)

- **Example problem:** A tunnel is to be driven through a slightly weathered granite where the strike is perpendicular to the tunnel axis and dipping at 60° against the direction of the drive. Index testing and logging of diamond drilled core give typical Point – load strength index value of 9 MPa and average RQD value of 60%. The slightly rough and slightly weathered joint with a separation of < 1 mm, are spaced at 300 mm. The joint surface is open (unfilled), persistence is 2.3 m. Tunneling conditions are anticipated to be wet. Determine RMR of the rock mass.

Source: Deb and Verma (2016)

Classification based on Rock Mass Rating (*RMR*) (contd...)

Source: Bieniawski (1989)

RMR table 1 : Classification parameters and their ratings

Parameter		Range of values						
Strength of intact rock material	Point load strength index (MPa)	>10	4 – 10	2 – 4	1 – 2	For the low range uniaxial compressive strength is preferred		
	Uniaxial compressive strength (MPa)	> 250	100 – 250	50 – 100	25 – 50	5 – 25	1 – 5	< 1
Rating		15	12	7	4	2	1	0
Drill core quality, RQD (%)		90 – 100	75 – 90	50 – 75	25 – 50	< 25		
Rating		20	17	13	8	3		
Spacing of discontinuities (m)		> 2	0.6 – 2	0.2 – 0.6	0.06 – 0.2	< 0.06		
Rating		20	15	10	8	5		
Condition of discontinuities (See RMR table 2)		Very rough surfaces; Not continuous; No separation; Unweathered wall rock	Slightly rough surfaces; Separation < 1 mm; Slightly weathered walls	Slightly rough surfaces; Separation < 1 mm; Highly weathered walls	Slickensided surfaces; or Gouge < 5 mm thick; or Separation 1 – 5 mm; Continuous	Soft gouge > 5 mm thick; or Separation > 5 mm; Continuous joints		
Rating		30	25	20	10	0		
Ground water	Inflow per 10 m tunnel length (l/m)	None	< 10	10 – 25	25 – 125	> 125		
	(Joint water pressure)/(Major Principal stress)	0	< 0.1	0.1 – 0.2	0.2 – 0.5	> 0.5		
	General conditions	Completely dry	Damp	Wet	Dripping	Flowing		
Rating		15	10	7	4	0		

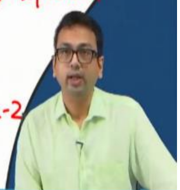
Classification based on Rock Mass Rating (*RMR*) (contd...)

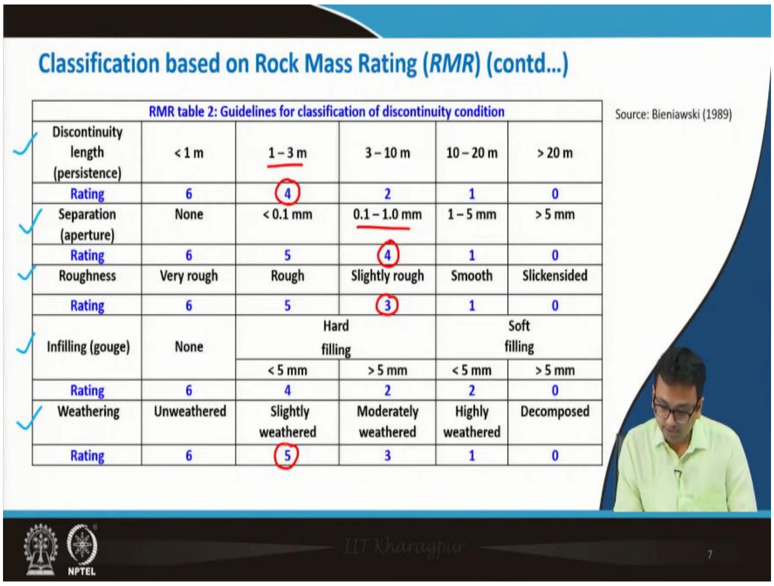
- Solution: As per RMR Table-3, for the condition where the strike is perpendicular to the tunnel axis and tunnel is to be driven against the dip, also dipping at 60° the description is 'Fair'

  Now, using RMR Table-4, the adjustment of rating is -5

  As per RMR Table-1, for the condition of discontinuities the Rating is 25 (Slightly rough, slightly weathered, separation < 1mm)

  Since we have detailed information about the condition of discontinuities, we should use RMR Table-2





RMR table 2: Guidelines for classification of discontinuity condition					
Discontinuity length (persistence)	< 1 m	1 – 3 m	3 – 10 m	10 – 20 m	> 20 m
Rating	6	4	2	1	0
Separation (aperture)	None	< 0.1 mm	0.1 – 1.0 mm	1 – 5 mm	> 5 mm
Rating	6	5	4	1	0
Roughness	Very rough	Rough	Slightly rough	Smooth	Slickensided
Rating	6	5	3	1	0
Infilling (gouge)	None	Hard filling		Soft filling	
		< 5 mm	> 5 mm	< 5 mm	> 5 mm
Rating	6	4	2	2	0
Weathering	Unweathered	Slightly weathered	Moderately weathered	Highly weathered	Decomposed
Rating	6	5	3	1	0

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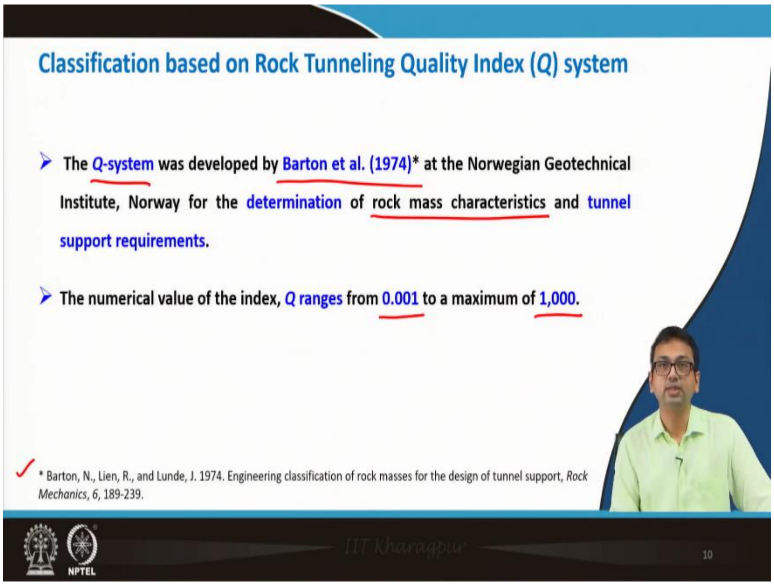

Hope doubts for the topic RMR system were cleared.

Next is our Q system. It is an important and useful classification system as far as the tunnel construction is concerned. Q system was developed by Barton et al. 1974 at the Norwegian Geotechnical Institute, Norway for determination of rock mass characteristics and tunnel support requirements. The numerical value of the Q index, ranges from 0.001 to maximum 1000.

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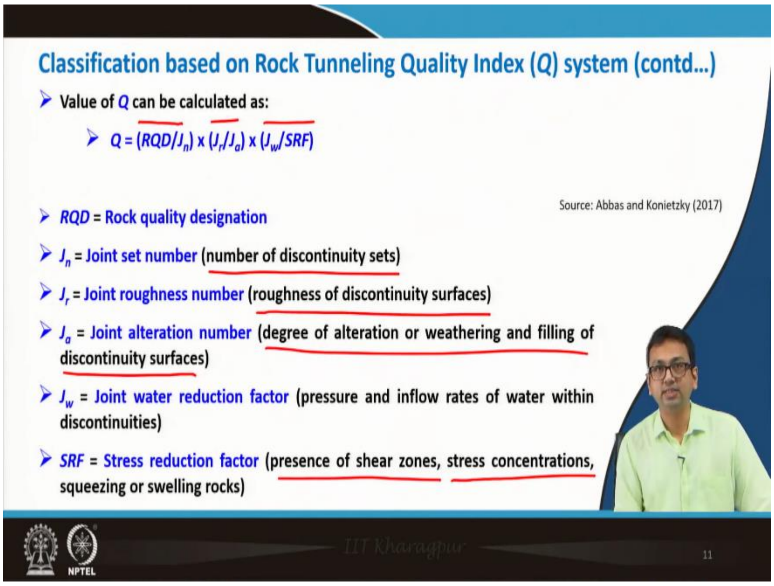

Now, value of Q can be calculated as

$$Q = (RQD/J_n) \times (J_r / J_a) \times (J_w / SRF)$$

where,

J_n is the join set number (it is the number of discontinuity sets)

J_r is the joint roughness number (roughness of discontinuities surfaces)

J_a is the joint alteration number (degree of alteration or weathering and filling of discontinuity surfaces)

J_w joint water reduction factor (pressure and inflow rates of water within discontinuities)

SRF is the stress reduction factor (presence of shear zones, stress concentrations and squeezing or swelling rocks)

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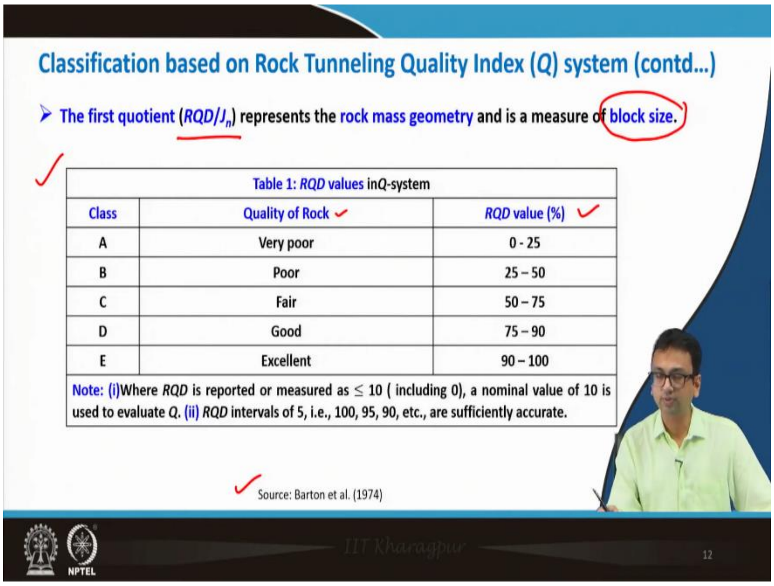

Class	Quality of Rock	RQD value (%)
A	Very poor	0 - 25
B	Poor	25 – 50
C	Fair	50 – 75
D	Good	75 – 90
E	Excellent	90 – 100

The table describing the RQD values corresponding quality of rock is used in Q-system. So, the table 1 is RQD values in Q-system, it is as per Barton et al. 1974.

The first quotient is RQD/J_n which represents the rock mass geometry and it is a measure of the block size. Using table 1 we can find RQD

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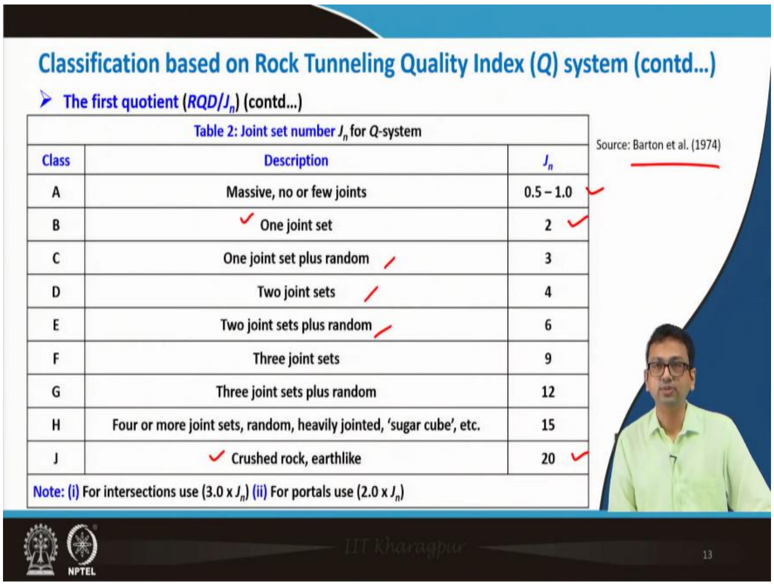

Class	Description	J_n
A	Massive, no or few joints	0.5 – 1.0
B	One joint set	2
C	One joint set plus random	3
D	Two joint sets	4
E	Two joint sets plus random	6
F	Three joint sets	9
G	Three joint sets plus random	12
H	Four or more joint sets, random, heavily jointed, 'sugar cube', etc.	15
J	Crushed rock, earthlike	20

Barton has again provided a table, table 2 for joint set number. here you see for massive or no or few joints, the J_n is 0.5-1.0 whereas for 1 joint set it is 2. Likewise, for crushed rock it is 20.

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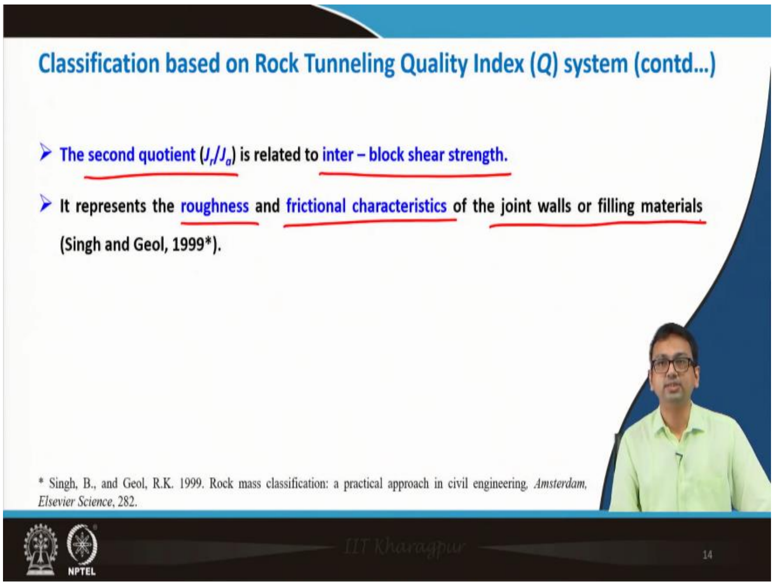

Now, next quotient is J_r / J_a. It is related to the inter-block shear strength. It represents the roughness and frictional characteristics of joint walls or filling materials.

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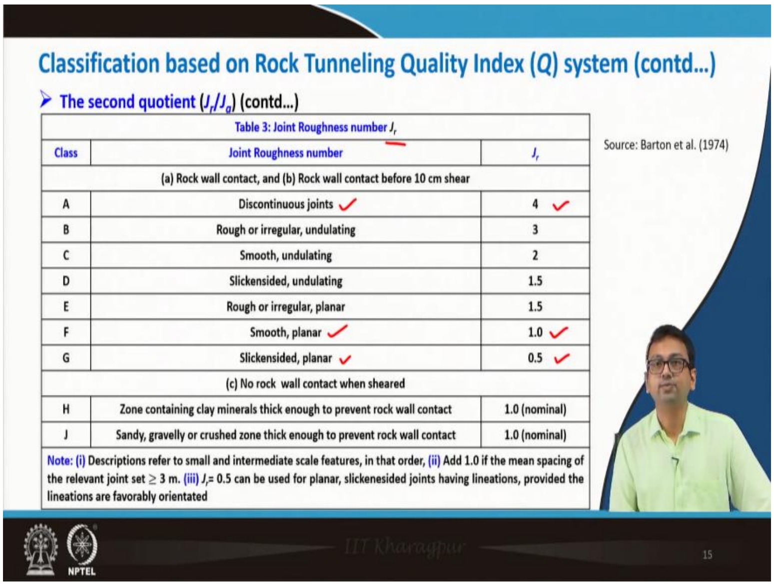

Table 3 and table 4 is provided by Barton et al. for the joint roughness number J_r and J_a respectively.

From table 3 for smooth or planar, you have to consider J_r as 1 and if it is slickensided planar then 0.5. Slickensided is nothing but you can think it like smooth surface. So, there it is 0.5. Based on given condition, you have to choose which Jr value is appropriate for you.

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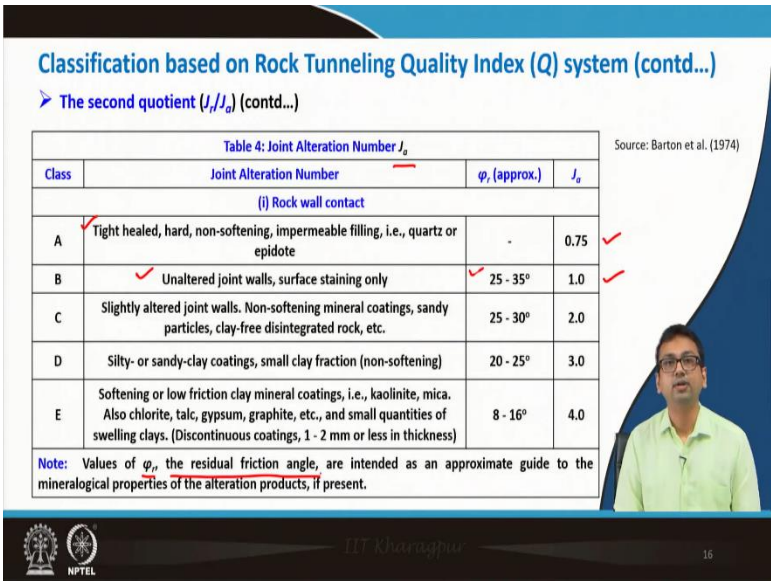

Similarly, for J_a table 4 is used. Here also you see detailed description like Class A it indicates tight, healed, hard, non-softening, impermeable filling that is quartz or epidote. For that case, your J_a is 0.75. Likewise, if it is the second one like unaltered joint walls, surface staining only then your J_a is 1 and ϕ_r means residual friction angle i.e. for the first condition it is 25 to 35 degrees. Due to the residual angle this table is of sheer importance.

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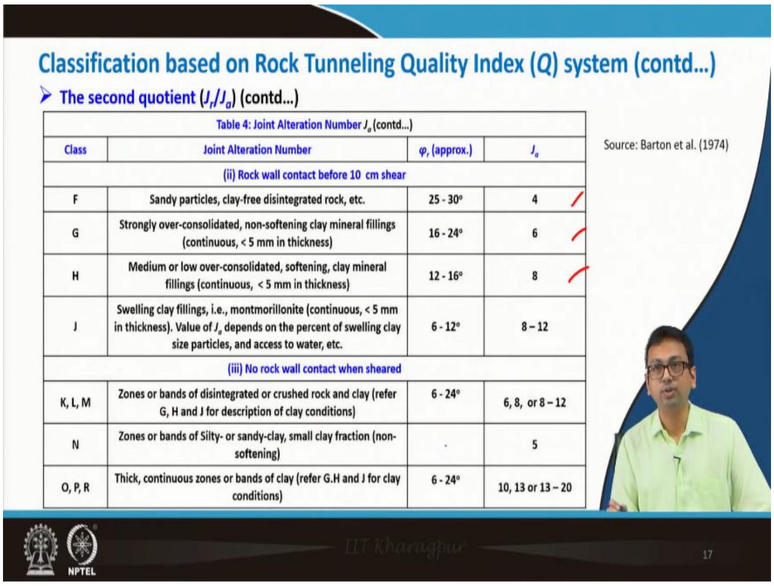

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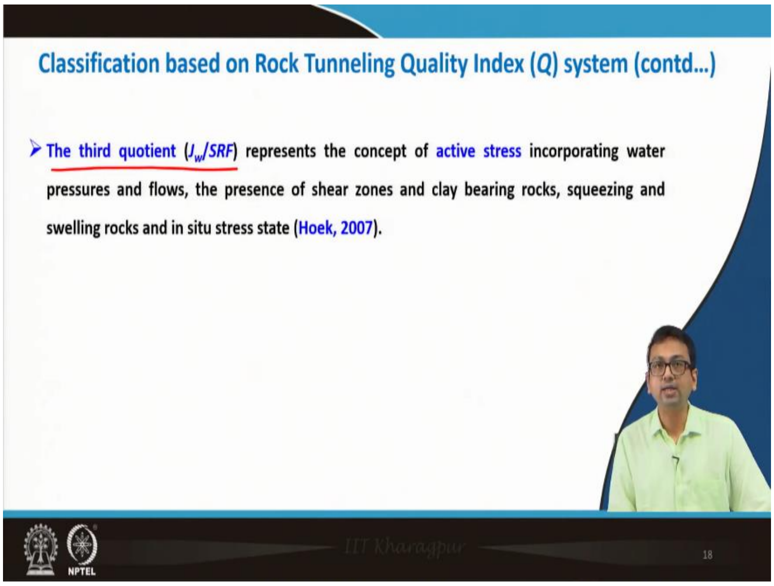

Third question is J_w/SRF, it presents the concept of active stress incorporating water pressures and flows, the presence of sheared zones and clay bearing rocks, squeezing and swelling rocks and in situ stress state.

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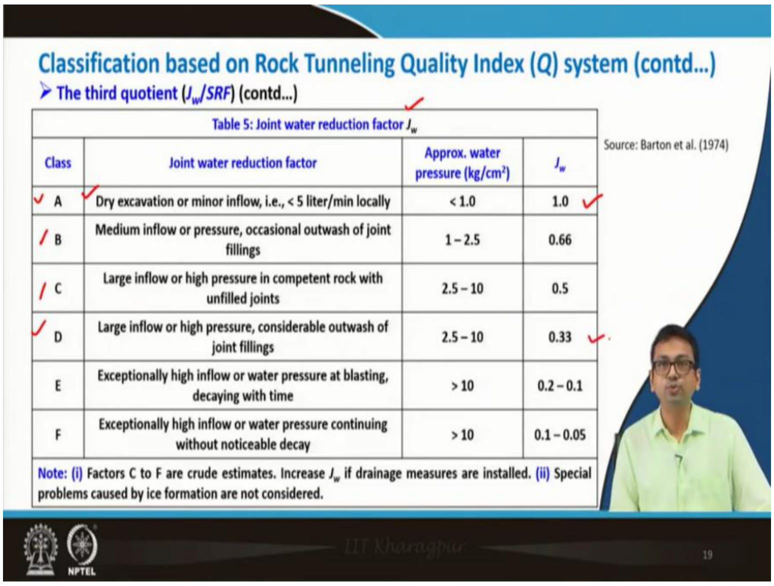

Now, again Barton et al. has provided table 5 for joint water reduction factor that is J_w and again, class A, B, C like that several classes are there. Now, if we consider the dry excavation or minor inflow that is less than 5 litres per minute locally then J_w is 1. Whereas, for class D large inflow or high pressure considerable outwash of joint fillings J_w is 0.33.

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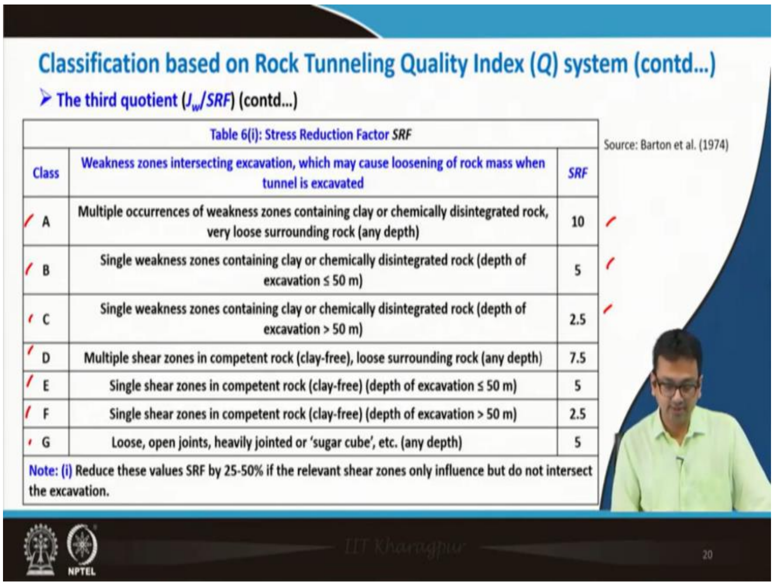

Table 6 is for stress reduction factor, SRF. So, again there are different classes A B C D and so on and corresponding SRF values are provided. In table 6(i) classes have description and corresponding SRF values but in table 6(ii) classes there is description, and two more columns along with SRF values. The other two values are σ_c/σ_1 and σ_t/σ_1 where σ_1 and

Predicting Landslides Using Contour Aligning Convolutional Neural Networks

by

Ainaz Hajimoradlou

B.Sc., Sharif University of Technology, 2017

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OF THE REQUIREMENTS FOR THE DEGREE OF

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σ_3 are maj or and minor principal stresses; σ_c and σ_t are unconfined compressive strength and tensile strength point load. Based on the these values SRF is to be chosen.

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Classification based on Rock Tunneling Quality Index (*Q*) system (contd...)

➤ **The third quotient (J_w/SRF) (contd...)**

Source: Barton et al. (1974)

Table 6(ii): Stress Reduction Factor *SRF* (contd...)				
Class	Competent rock, rock stress problems	σ_c / σ_1	σ_t / σ_1	*SRF*
H	Low stress, near surface	> 200	> 13	2.5
J	Medium stress	200 – 10	13 – 0.66	1
K	High stress, very tight structure (Usually favorable to stability, may be unfavorable to wall stability)	10 – 5	0.66 – 0.33	0.5 – 2
L	Mild rock burst (massive rock)	5 – 2.5	0.33 – 0.16	5 – 10
M	Heavy rock burst (massive rock)	< 2.5	< 0.16	10 – 20

Note: **(ii)** For strongly anisotropic stress field (if measured): when $5 \le \sigma_1/\sigma_3 \le 10$, reduce σ_c to $0.8\sigma_c$ and σ_t to $0.8\sigma_t$; when $\sigma_1/\sigma_3 > 10$, reduce σ_c to $0.6\sigma_c$ and σ_t to $0.6\sigma_t$; where σ_c is unconfined compressive strength, σ_1 and σ_3 are major and minor principal stresses, and σ_t is tensile strength (point load). **(iii)** Few case records are available where the depth of crown below the surface is less than span width. Suggest increase in *SRF* from 2.5 to 5 for such cases (refer H).

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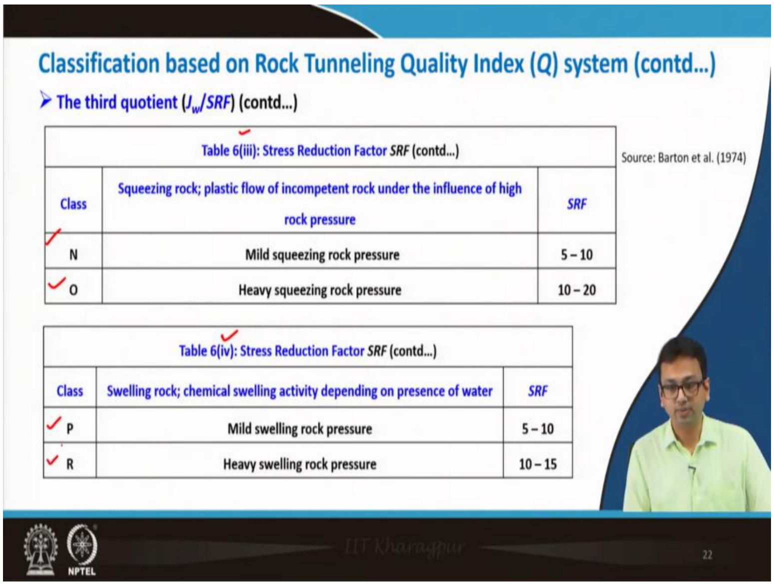

Similarly, this table 6(iii) is giving SRF for classes N and O and table 6(iv) is giving SRF for classes P and R.

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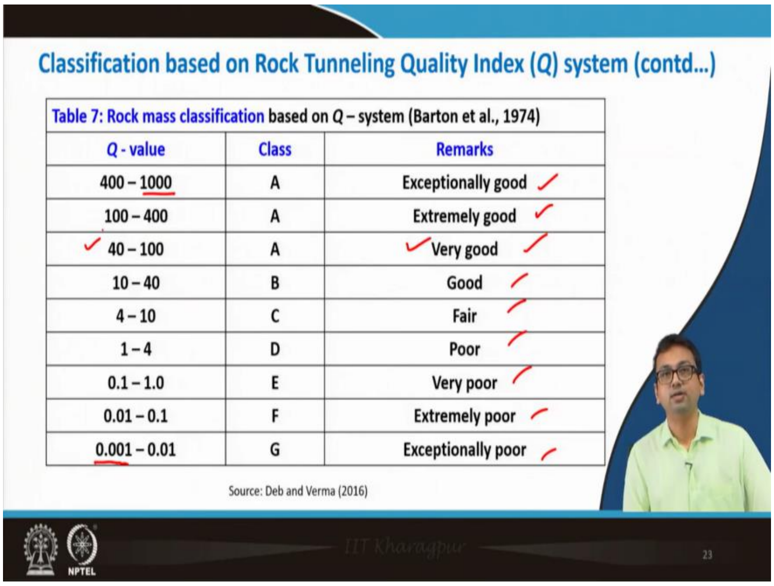

So, after using all the six tables, we can finally obtain our final Q-value which ranges from 0.001 to 1000. From table 7 we can get the class and remarks based on the Q value. So, if Q-value is very less, then exceptionally poor and if Q-value is exceptionally good then that range is 400 to 1000 whereas if it is very good category, then range is 40 to 100.

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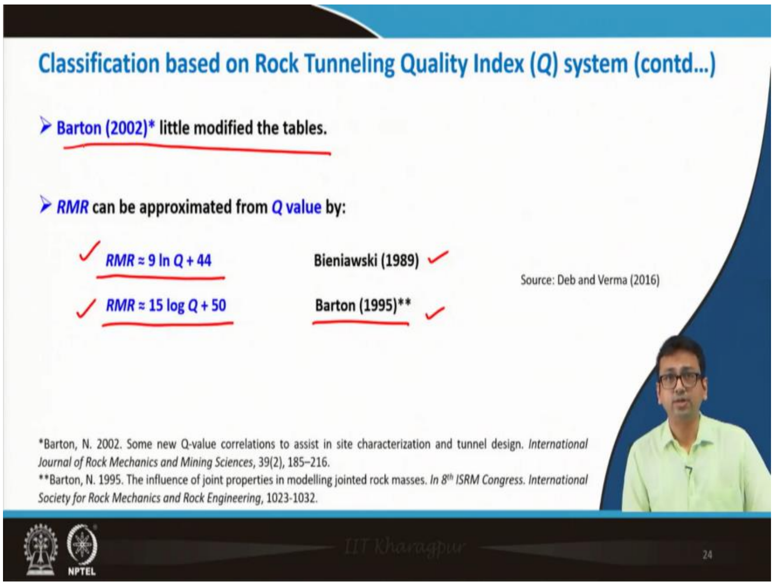

So, now in 2002, Barton further modified the tables but remember that Barton et al. 1974 was the first one and after that little modification.

RMR can be approximated from Q-value.

$$RMR = 9 \ln Q + 44 \quad \text{(Bieniawski 1989)}$$

$$RMR = 15 \log Q + 50 \text{ (Barton 1995)}$$

We can understand if we obtain Q-value we can get our RMR or vice versa.

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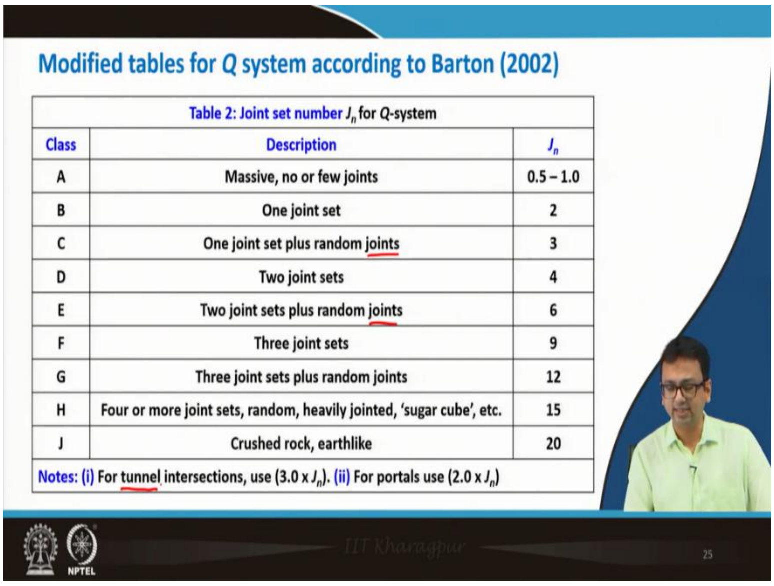

Table 2: Joint set number J_n for Q-system

Class	Description	J_n
A	Massive, no or few joints	0.5 – 1.0
B	One joint set	2
C	One joint set plus random joints	3
D	Two joint sets	4
E	Two joint sets plus random joints	6
F	Three joint sets	9
G	Three joint sets plus random joints	12
H	Four or more joint sets, random, heavily jointed, 'sugar cube', etc.	15
J	Crushed rock, earthlike	20

Notes: (i) For tunnel intersections, use (3.0 x J_n). (ii) For portals use (2.0 x J_n)

As stated Barton 2002 modified tables are given in the slides. Tables 1 to 5 are almost same as Barton et al. 1974 tables, with some minor changes (the ones with the change are shown in the slides)

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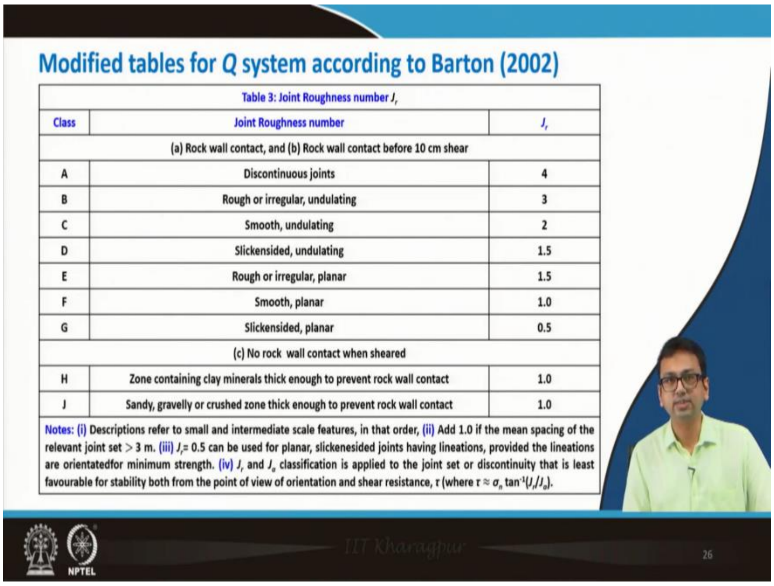

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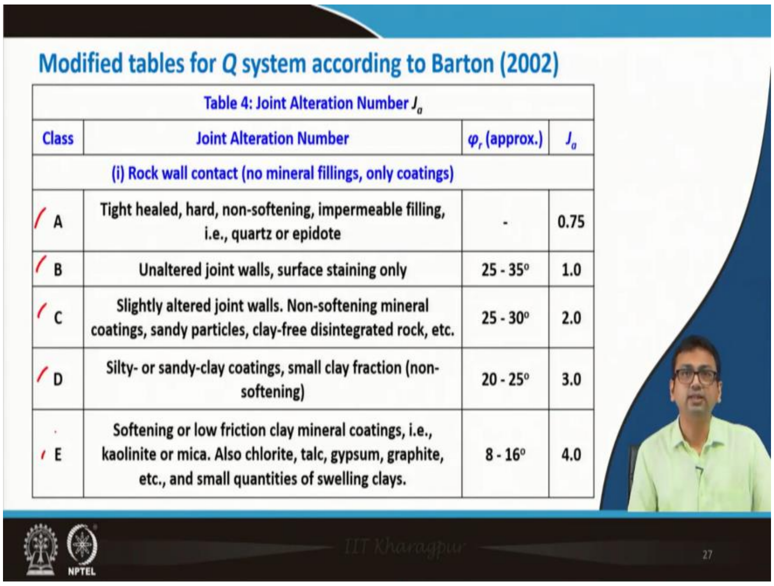

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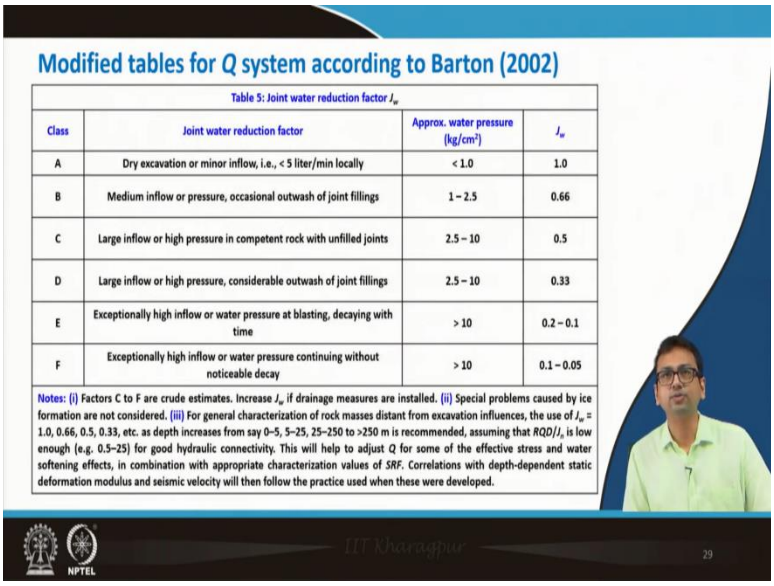

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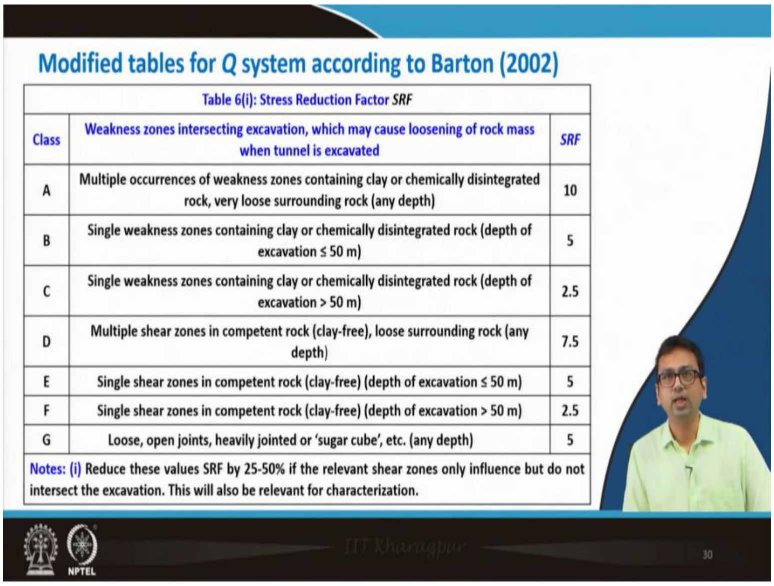

SRF is for table 6, in case of table 6 again little modifications have been made. Especially in table 6(iii) a new column is added which is σ_θ / σ_c where σ_θ is nothing but the maximum tangential stress. Also, a new class S was added in table 6(iv).

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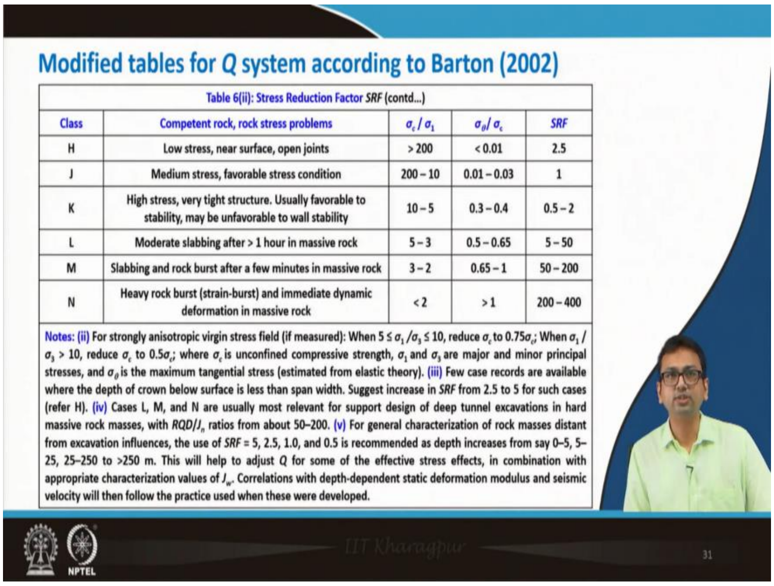

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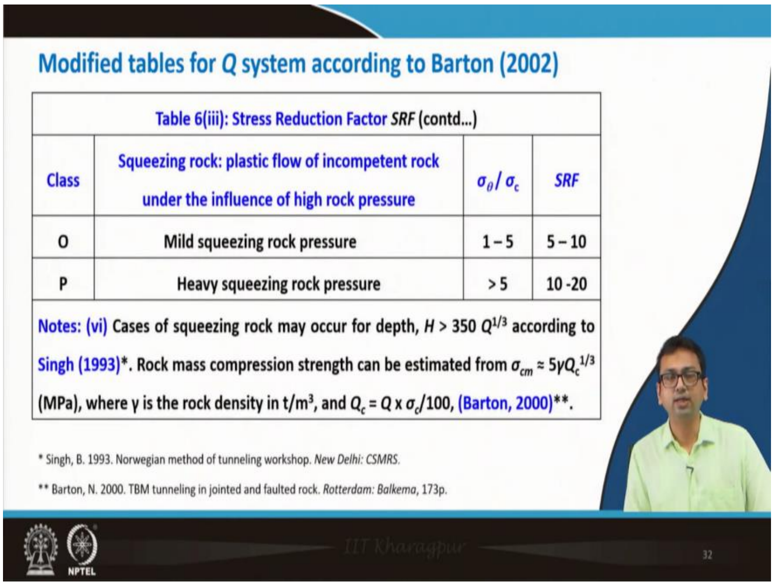

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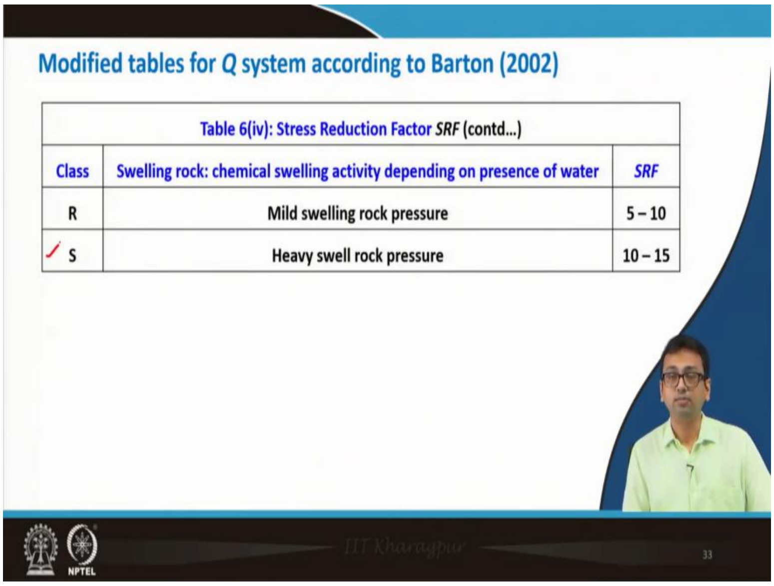
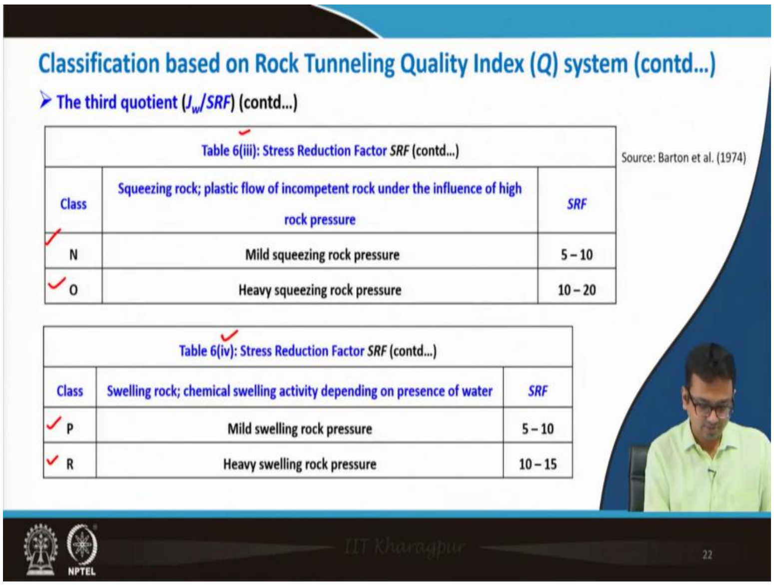


Modified tables for *Q* system according to Barton (2002)

Table 6(iv): Stress Reduction Factor *SRF* (contd...)		
Class	Swelling rock: chemical swelling activity depending on presence of water	*SRF*
R	Mild swelling rock pressure	5 – 10
S	Heavy swell rock pressure	10 – 15



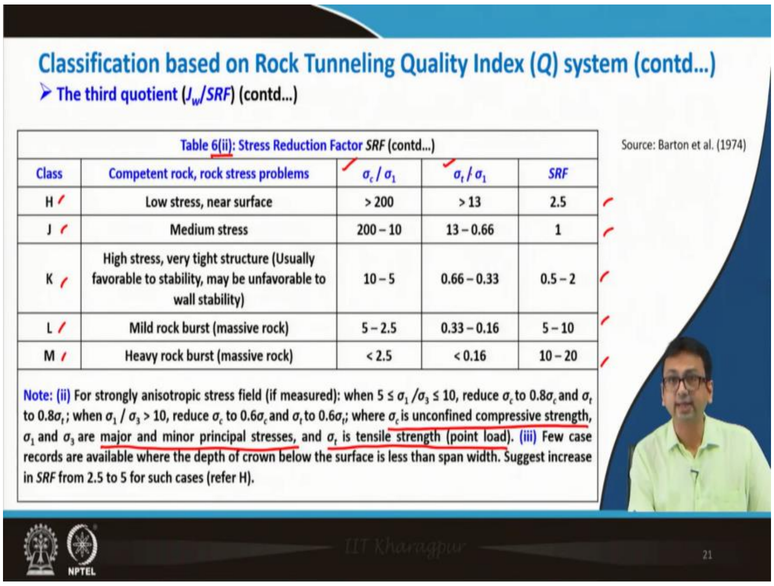
Classification based on Rock Tunneling Quality Index (*Q*) system (contd...)

➢ The third quotient (J_w/*SRF*) (contd...)

Table 6(iii): Stress Reduction Factor *SRF* (contd...)		
Class	Squeezing rock; plastic flow of incompetent rock under the influence of high rock pressure	*SRF*
N	Mild squeezing rock pressure	5 – 10
O	Heavy squeezing rock pressure	10 – 20

Source: Barton et al. (1974)

Table 6(iv): Stress Reduction Factor *SRF* (contd...)		
Class	Swelling rock; chemical swelling activity depending on presence of water	*SRF*
P	Mild swelling rock pressure	5 – 10
R	Heavy swelling rock pressure	10 – 15



Classification based on Rock Tunneling Quality Index (*Q*) system (contd...)

➢ The third quotient (J_w/*SRF*) (contd...)

Table 6(ii): Stress Reduction Factor *SRF* (contd...)				
Class	Competent rock, rock stress problems	σ_c / σ_1	σ_t / σ_1	*SRF*
H	Low stress, near surface	> 200	> 13	2.5
J	Medium stress	200 – 10	13 – 0.66	1
K	High stress, very tight structure (Usually favorable to stability, may be unfavorable to wall stability)	10 – 5	0.66 – 0.33	0.5 – 2
L	Mild rock burst (massive rock)	5 – 2.5	0.33 – 0.16	5 – 10
M	Heavy rock burst (massive rock)	< 2.5	< 0.16	10 – 20

Note: (ii) For strongly anisotropic stress field (if measured): when $5 \leq \sigma_1 / \sigma_3 \leq 10$, reduce σ_c to $0.8\sigma_c$ and σ_t to $0.8\sigma_t$; when $\sigma_1 / \sigma_3 > 10$, reduce σ_c to $0.6\sigma_c$ and σ_t to $0.6\sigma_t$; where σ_c is unconfined compressive strength, σ_1 and σ_3 are major and minor principal stresses, and σ_t is tensile strength (point load). (iii) Few case records are available where the depth of crown below the surface is less than span width. Suggest increase in *SRF* from 2.5 to 5 for such cases (refer H).

Source: Barton et al. (1974)

(Refer Slide Time: 39:28)

So, in our next lecture, we will solve a problem to clear the concepts. We will also discuss about GSI system in our next class along with completion of Q-system, we will discuss about the GSI system also. Thank you.