Rock Mechanics and Tunneling
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Lecture 26
Rock mass classification (continued)

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Hello everyone. I welcome all of you to the fifth lecture of module 5. So, in module 5, we are discussing about the rock mass classification and this will be the last lecture of this module.

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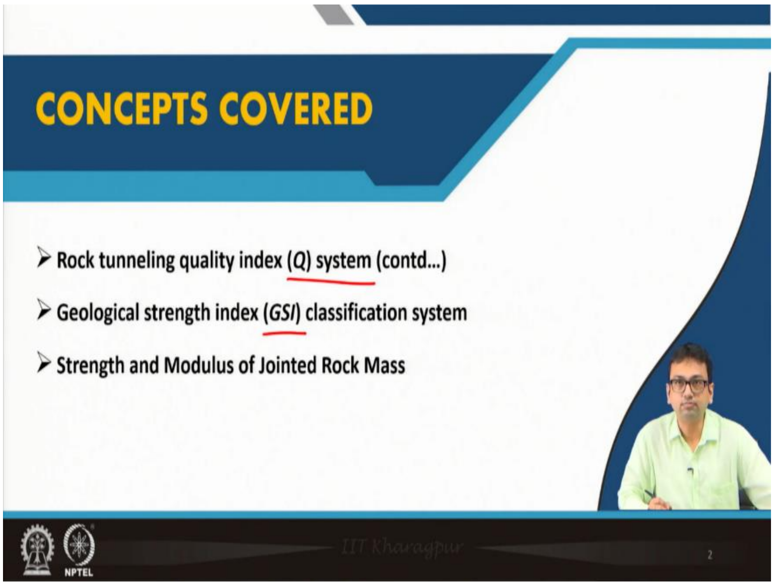

In this lecture a problem will be solved on Q-system which was discussed in detail in the previous lecture.

Then we will learn another classification system that is called the geological strength index, GSI classification system. We will see its importance later when we will learn about the weak round hill criteria. And after learning these two things, at the end, we will little bit discuss about the strength and modulus of jointed rock mass.

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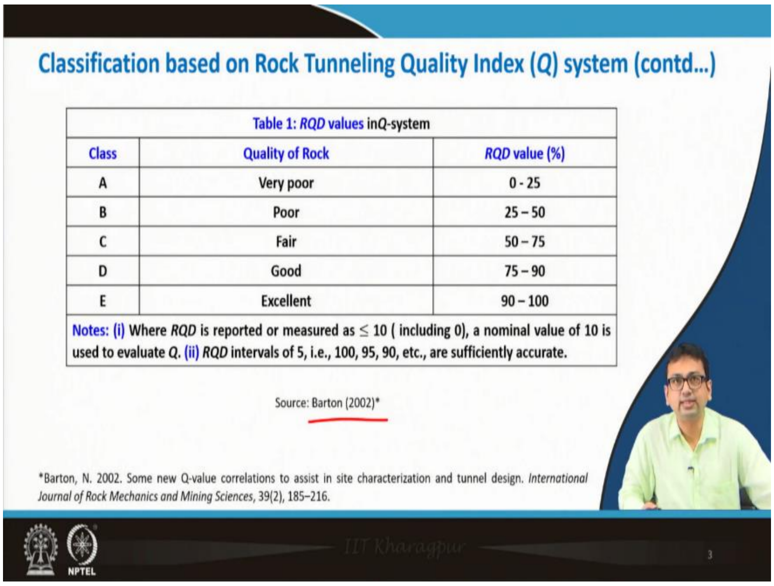

To solve the table Barton 2002 tables (modified) have been kept.

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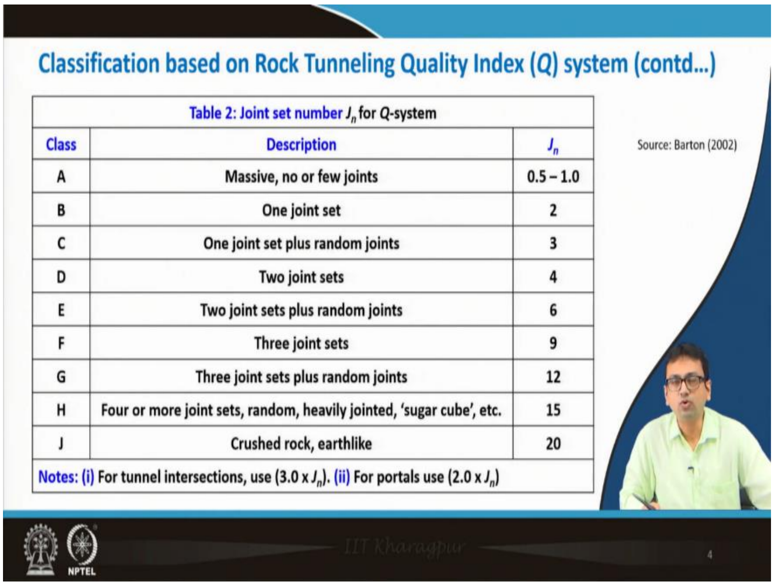

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Classification based on Rock Tunneling Quality Index (Q) system (contd...)

Source: Barton (2002)

Table 3: Joint Roughness number J_r		
Class	Joint Roughness number	J_r
(a) Rock wall contact, and (b) Rock wall contact before 10 cm shear		
A	Discontinuous joints	4
B	Rough or irregular, undulating	3
C	Smooth, undulating	2
D	Slickensided, undulating	1.5
E	Rough or irregular, planar	1.5
F	Smooth, planar	1.0
G	Slickensided, planar	0.5
(c) No rock wall contact when sheared		
H	Zone containing clay minerals thick enough to prevent rock wall contact	1.0
J	Sandy, gravelly or crushed zone thick enough to prevent rock wall contact	1.0

Notes: (i) Descriptions refer to small and intermediate scale features, in that order, (ii) Add 1.0 if the mean spacing of the relevant joint set > 3 m. (iii) J_r= 0.5 can be used for planar, slickenesided joints having lineations, provided the lineations are orientatedfor minimum strength. (iv) J_r and J_a classification is applied to the joint set or discontinuity that is least favourable for stability both from the point of view of orientation and shear resistance, τ (where $\tau \approx \sigma_n \tan^{-1}(J_r/J_a)$.

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

Source: Barton (2002)

Table 4: Joint Alteration Number J_a			
Class	Joint Alteration Number	φ_r (approx.)	J_a
(i) Rock wall contact (no mineral fillings, only coatings)			
A	Tight healed, hard, non-softening, impermeable filling, i.e., quartz or epidote	-	0.75
B	Unaltered joint walls, surface staining only	25 - 35°	1.0
C	Slightly altered joint walls. Non-softening mineral coatings, sandy particles, clay-free disintegrated rock, etc.	25 - 30°	2.0
D	Silty- or sandy-clay coatings, small clay fraction (non-softening)	20 - 25°	3.0
E	Softening or low friction clay mineral coatings, i.e., kaolinite or mica. Also chlorite, talc, gypsum, graphite, etc., and small quantities of swelling clays.	8 - 16°	4.0

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

Source: Barton (2002)

Table 4: Joint Alteration Number J_a (contd...)			
Class	Joint Alteration Number	φ_r (approx.)	J_a
(ii) Rock wall contact before 10 cm shear (thin mineral fillings)			
F	Sandy particles, clay-free disintegrated rock, etc.	25 - 30°	4
G	Strongly over-consolidated, non-softening clay mineral fillings (continuous, but < 5 mm in thickness)	16 - 24°	6
H	Medium or low over-consolidation, softening, clay mineral fillings (continuous, but < 5 mm in thickness)	12 - 16°	8
J	Swelling clay fillings, i.e., montmorillonite (continuous, but < 5 mm in thickness). Value of J_a depends on the percent of swelling clay size particles, and access to water, etc.	6 - 12°	8 – 12
(iii) No rock wall contact when sheared (thick mineral fillings)			
K, L, M	Zones or bands of disintegrated or crushed rock and clay (refer G, H and J for description of clay conditions)	6 - 24°	6, 8, or 8 – 12
N	Zones or bands of Silty- or sandy-clay, small clay fraction (non-softening)	-	5
O, P, R	Thick, continuous zones or bands of clay (refer G.H and J for description of clay conditions)	6 - 24°	10, 13 or 13 – 20

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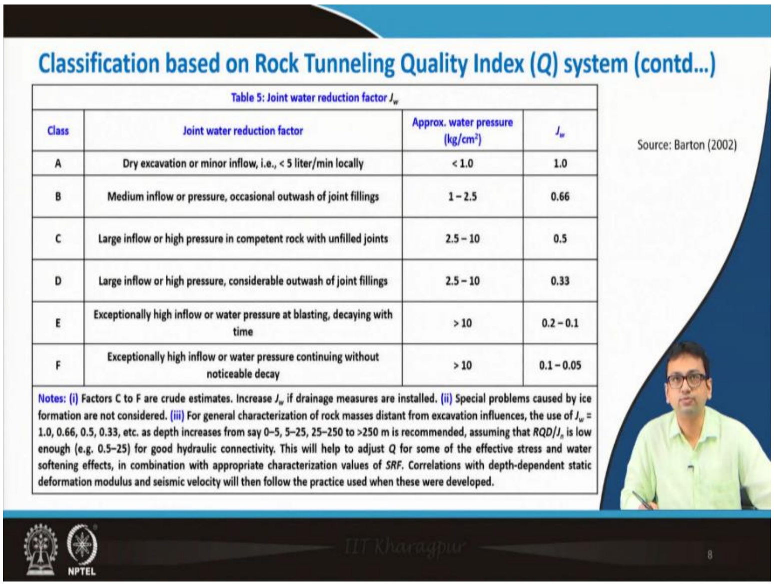

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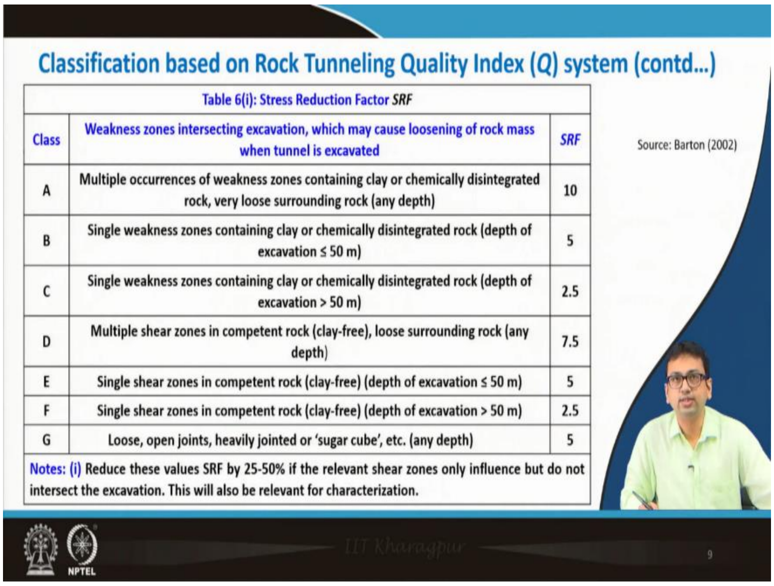

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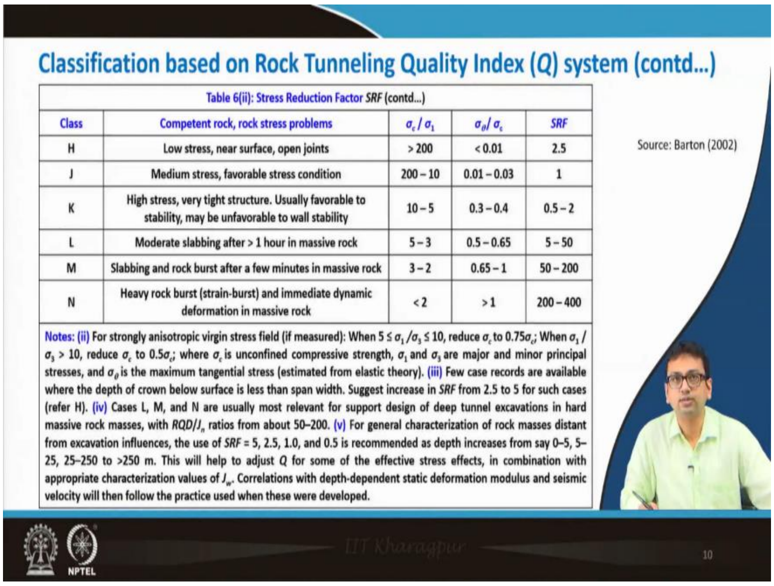


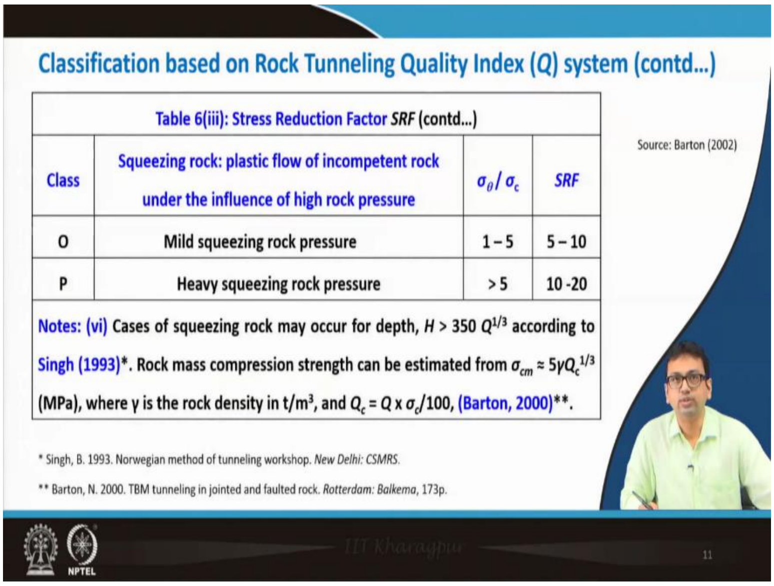
Classification based on Rock Tunneling Quality Index (Q) system (contd...)

Table 6(ii): Stress Reduction Factor *SRF* (contd...)

Class	Competent rock, rock stress problems	σ_c / σ_1	σ_θ / σ_c	*SRF*
H	Low stress, near surface, open joints	> 200	< 0.01	2.5
J	Medium stress, favorable stress condition	200 – 10	0.01 – 0.03	1
K	High stress, very tight structure. Usually favorable to stability, may be unfavorable to wall stability	10 – 5	0.3 – 0.4	0.5 – 2
L	Moderate slabbing after > 1 hour in massive rock	5 – 3	0.5 – 0.65	5 – 50
M	Slabbing and rock burst after a few minutes in massive rock	3 – 2	0.65 – 1	50 – 200
N	Heavy rock burst (strain-burst) and immediate dynamic deformation in massive rock	< 2	> 1	200 – 400

Notes: (ii) For strongly anisotropic virgin stress field (if measured): When $5 \leq \sigma_1 / \sigma_3 \leq 10$, reduce σ_c to $0.75\sigma_c$; When $\sigma_1 / \sigma_3 > 10$, reduce σ_c to $0.5\sigma_c$; where σ_c is unconfined compressive strength, σ_1 and σ_3 are major and minor principal stresses, and σ_θ is the maximum tangential stress (estimated from elastic theory). (iii) Few case records are available where the depth of crown below surface is less than span width. Suggest increase in *SRF* from 2.5 to 5 for such cases (refer H). (iv) Cases L, M, and N are usually most relevant for support design of deep tunnel excavations in hard massive rock masses, with RQD/J_n ratios from about 50–200. (v) For general characterization of rock masses distant from excavation influences, the use of *SRF* = 5, 2.5, 1.0, and 0.5 is recommended as depth increases from say 0–5, 5–25, 25–250 to >250 m. This will help to adjust Q for some of the effective stress effects, in combination with appropriate characterization values of J_w. Correlations with depth-dependent static deformation modulus and seismic velocity will then follow the practice used when these were developed.

Source: Barton (2002)



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

Table 6(iii): Stress Reduction Factor *SRF* (contd...)

Class	Squeezing rock: plastic flow of incompetent rock under the influence of high rock pressure	σ_θ / σ_c	*SRF*
O	Mild squeezing rock pressure	1 – 5	5 – 10
P	Heavy squeezing rock pressure	> 5	10 -20

Notes: (vi) Cases of squeezing rock may occur for depth, $H > 350\ Q^{1/3}$ according to Singh (1993)*. Rock mass compression strength can be estimated from $\sigma_{cm} \approx 5\gamma Q_c^{1/3}$ (MPa), where γ is the rock density in t/m^3, and $Q_c = Q \times \sigma_c/100$, (Barton, 2000)**.

Source: Barton (2002)

* Singh, B. 1993. Norwegian method of tunneling workshop. *New Delhi: CSMRS*.

** Barton, N. 2000. TBM tunneling in jointed and faulted rock. *Rotterdam: Balkema*, 173p.

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

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

Source: Barton (2002)

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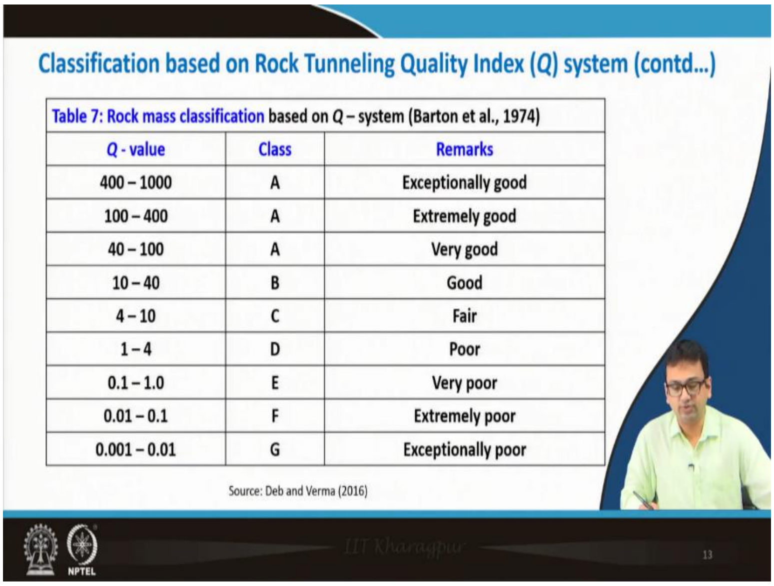

Table 7: Rock mass classification based on *Q* – system (Barton et al., 1974)

Q - value	Class	Remarks
400 – 1000	A	Exceptionally good
100 – 400	A	Extremely good
40 – 100	A	Very good
10 – 40	B	Good
4 – 10	C	Fair
1 – 4	D	Poor
0.1 – 1.0	E	Very poor
0.01 – 0.1	F	Extremely poor
0.001 – 0.01	G	Exceptionally poor

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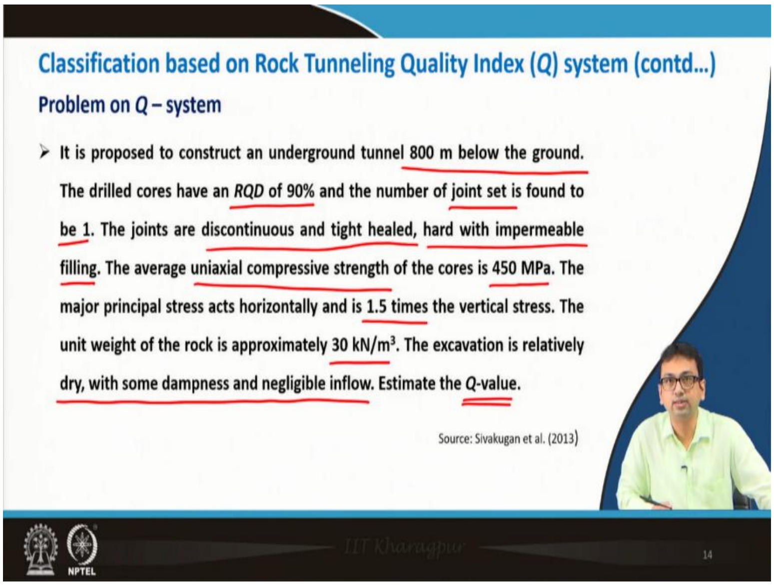

Example problem: It is proposed to construct an underground tunnel 800 m below the ground. The drilled cores have an RQD of 90 % and the number of joint set is found to be 1. The joints are discontinuous and tight healed, hard with impermeable filling. The average uniaxial compressive strength of the core is 450 MPa. The major principal stress acts horizontally and is 1.5 times the vertical stress. The unit weight of the rock is approximately 30 kN/m^3. The excavation is relatively dry with some dampness and negligible inflow, so dry with some dampness and negligible inflow. Estimate Q-value.

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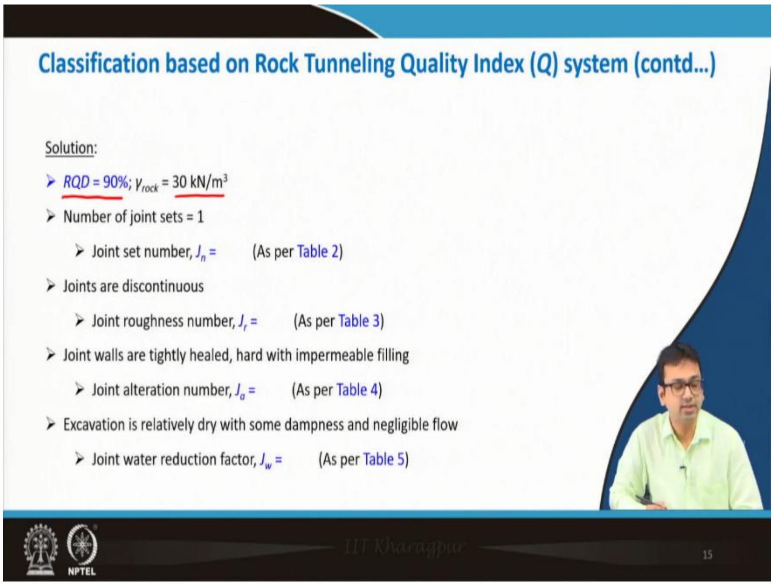

Solution:

- RQD= 90%; γ_{rock}= 30kN/m^3
- Number of joint sets= 1
  - Joint set number, J_n= **2** (As per table 2)
- Joints are discontinuous
  - Joint roughness number, J_r= **4** (As per table 3)
- Joint walls are tight healed, hard with impermeable filling
  - Joint alteration number, J_a= **0.75** (As per table 4)
- Excavation is relatively dry with some dampness and negligible inflow
  - Joint water reduction factor, J_w= **1** (As per table 5)
- Vertical stress at the depth (z) of 800 m (minor pribncipal stress, σ_3)

  = γ_{rock} *(z) = 30*800 = 24000 kPa= **24 MPa**
- The major principal stress (σ_1) =1.5 σ_3= 1.5*24= **36 MPa**
- Uniaxial compressive strength of rock (σ_c) = **450 MPa**
- So, σ_c/ σ_1 = 450/36 = **12.5**
- Rock component class -J; strength reduction factor, SRF= **1** (As per table 6(ii))
- Q value $= (RQD/J_n) \times (J_r/J_a) \times (J_w / SRF)$ = (90/2)(4/0.75)(1/1)= **240**
- As per table 7, the rock mass quality is **extremely good (class A)**

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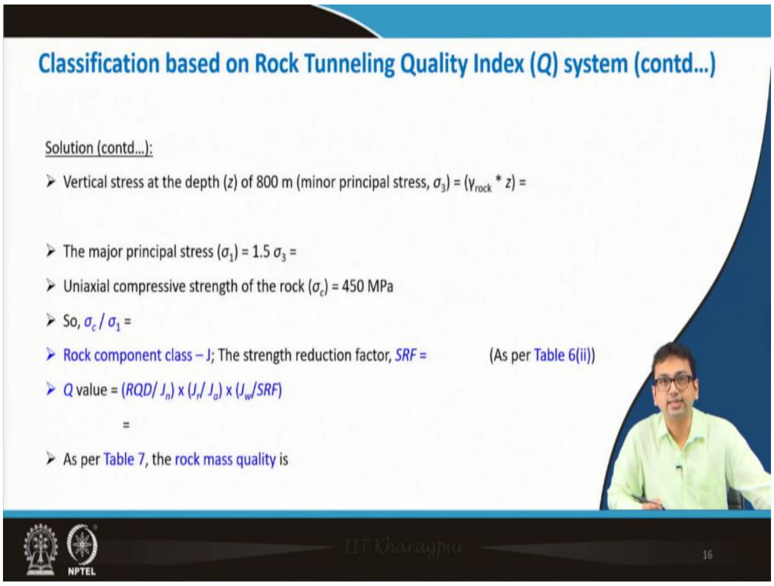

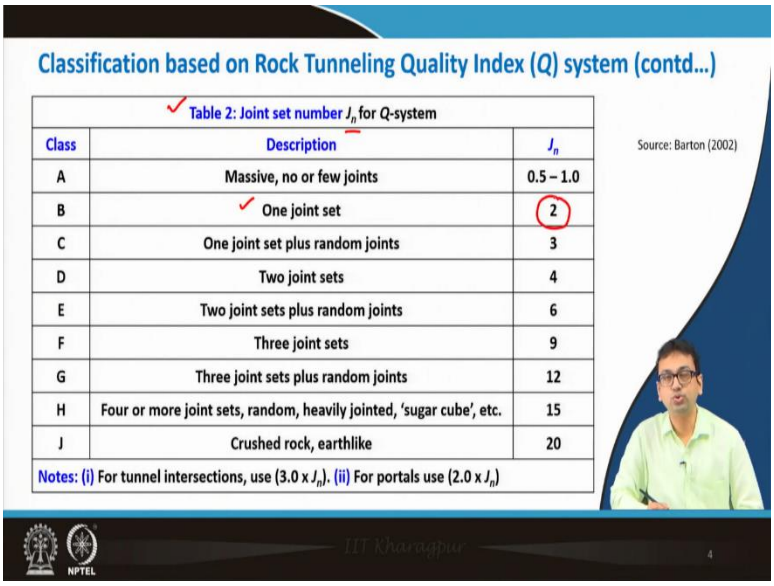

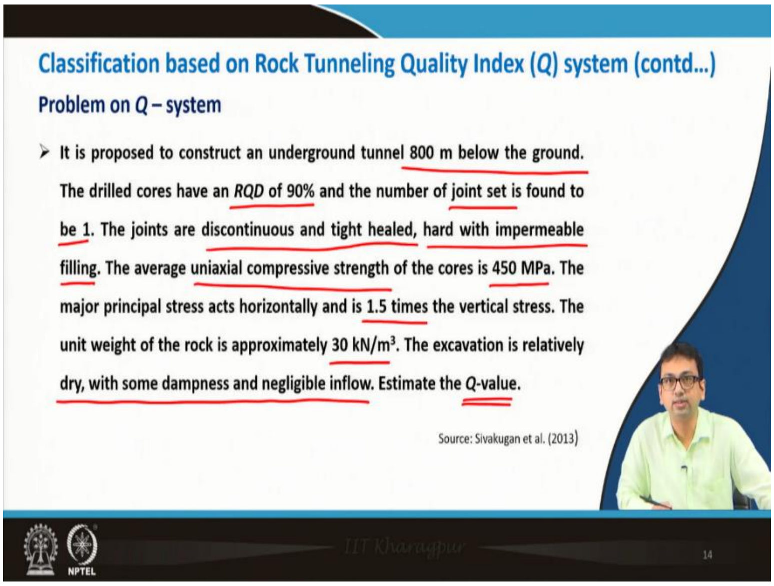

Classification based on Rock Tunneling Quality Index (*Q*) system (contd...)

Table 3: Joint Roughness number J_r

Class	Joint Roughness number	J_r
(a) Rock wall contact, and (b) Rock wall contact before 10 cm shear		
A	Discontinuous joints	4
B	Rough or irregular, undulating	3
C	Smooth, undulating	2
D	Slickensided, undulating	1.5
E	Rough or irregular, planar	1.5
F	Smooth, planar	1.0
G	Slickensided, planar	0.5
(c) No rock wall contact when sheared		
H	Zone containing clay minerals thick enough to prevent rock wall contact	1.0
J	Sandy, gravelly or crushed zone thick enough to prevent rock wall contact	1.0

Notes: (i) Descriptions refer to small and intermediate scale features, in that order, (ii) Add 1.0 if the mean spacing of the relevant joint set > 3 m. (iii) J_r= 0.5 can be used for planar, slickenesided joints having lineations, provided the lineations are orientatedfor minimum strength. (iv) J_r and J_a classification is applied to the joint set or discontinuity that is least favourable for stability both from the point of view of orientation and shear resistance, τ (where $\tau \approx \sigma_n \tan^{-1}(J_r/J_a)$.

Source: Barton (2002)

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

Table 4: Joint Alteration Number J_a

Class	Joint Alteration Number	φ_r (approx.)	J_a
(i) Rock wall contact (no mineral fillings, only coatings)			
A	Tight healed, hard, non-softening, impermeable filling, i.e., quartz or epidote	-	0.75
B	Unaltered joint walls, surface staining only	25 - 35°	1.0
C	Slightly altered joint walls. Non-softening mineral coatings, sandy particles, clay-free disintegrated rock, etc.	25 - 30°	2.0
D	Silty- or sandy-clay coatings, small clay fraction (non-softening)	20 - 25°	3.0
E	Softening or low friction clay mineral coatings, i.e., kaolinite or mica. Also chlorite, talc, gypsum, graphite, etc., and small quantities of swelling clays.	8 - 16°	4.0

Source: Barton (2002)

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

Table 5: Joint water reduction factor J_w

Class	Joint water reduction factor	Approx. water pressure (kg/cm^2)	J_w
A	Dry excavation or minor inflow, i.e., < 5 liter/min locally	< 1.0	1.0
B	Medium inflow or pressure, occasional outwash of joint fillings	1 – 2.5	0.66
C	Large inflow or high pressure in competent rock with unfilled joints	2.5 – 10	0.5
D	Large inflow or high pressure, considerable outwash of joint fillings	2.5 – 10	0.33
E	Exceptionally high inflow or water pressure at blasting, decaying with time	> 10	0.2 – 0.1
F	Exceptionally high inflow or water pressure continuing without noticeable decay	> 10	0.1 – 0.05

Notes: (i) Factors C to F are crude estimates. Increase J_w if drainage measures are installed. (ii) Special problems caused by ice formation are not considered. (iii) For general characterization of rock masses distant from excavation influences, the use of J_w = 1.0, 0.66, 0.5, 0.33, etc. as depth increases from say 0–5, 5–25, 25–250 to >250 m is recommended, assuming that RQD/J_n is low enough (e.g. 0.5–25) for good hydraulic connectivity. This will help to adjust *Q* for some of the effective stress and water softening effects, in combination with appropriate characterization values of *SRF*. Correlations with depth-dependent static deformation modulus and seismic velocity will then follow the practice used when these were developed.

Source: Barton (2002)

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

Problem on Q – system

Solution:

- $RQD = 90\%$; $\gamma_{rock} = 30$ kN/m^3
- Number of joint sets = 1
  - Joint set number, J_n = 2 (As per Table 2)
- Joints are discontinuous
  - Joint roughness number, J_r = 4 (As per Table 3)
- Joint walls are tightly healed, hard with impermeable filling
  - Joint alteration number, J_a = 0.75 (As per Table 4)
- Excavation is relatively dry with some dampness and negligible flow
  - Joint water reduction factor, J_w = 1 (As per Table 5)

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

Table 6(i): Stress Reduction Factor *SRF*

Class	Weakness zones intersecting excavation, which may cause loosening of rock mass when tunnel is excavated	*SRF*
A	Multiple occurrences of weakness zones containing clay or chemically disintegrated rock, very loose surrounding rock (any depth)	10
B	Single weakness zones containing clay or chemically disintegrated rock (depth of excavation ≤ 50 m)	5
C	Single weakness zones containing clay or chemically disintegrated rock (depth of excavation > 50 m)	2.5
D	Multiple shear zones in competent rock (clay-free), loose surrounding rock (any depth)	7.5
E	Single shear zones in competent rock (clay-free) (depth of excavation ≤ 50 m)	5
F	Single shear zones in competent rock (clay-free) (depth of excavation > 50 m)	2.5
G	Loose, open joints, heavily jointed or 'sugar cube', etc. (any depth)	5

Notes: (i) Reduce these values SRF by 25-50% if the relevant shear zones only influence but do not intersect the excavation. This will also be relevant for characterization.

Source: Barton (2002)

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

Table 6(ii): Stress Reduction Factor *SRF* (contd...)

Class	Competent rock, rock stress problems	σ_c / σ_1	σ_θ / σ_c	*SRF*
H	Low stress, near surface, open joints	> 200	< 0.01	2.5
J	Medium stress, favorable stress condition	200 – 10	0.01 – 0.03	1
K	High stress, very tight structure. Usually favorable to stability, may be unfavorable to wall stability	10 – 5	0.3 – 0.4	0.5 – 2
L	Moderate slabbing after > 1 hour in massive rock	5 – 3	0.5 – 0.65	5 – 50
M	Slabbing and rock burst after a few minutes in massive rock	3 – 2	0.65 – 1	50 – 200
N	Heavy rock burst (strain-burst) and immediate dynamic deformation in massive rock	< 2	> 1	200 – 400

Notes: (ii) For strongly anisotropic virgin stress field (if measured): When $5 \leq \sigma_1 / \sigma_3 \leq 10$, reduce σ_c to $0.75\sigma_c$; When $\sigma_1 / \sigma_3 > 10$, reduce σ_c to $0.5\sigma_c$; where σ_c is unconfined compressive strength, σ_1 and σ_3 are major and minor principal stresses, and σ_θ is the maximum tangential stress (estimated from elastic theory). (iii) Few case records are available where the depth of crown below surface is less than span width. Suggest increase in *SRF* from 2.5 to 5 for such cases (refer H). (iv) Cases L, M, and N are usually most relevant for support design of deep tunnel excavations in hard massive rock masses, with RQD/J_n ratios from about 50–200. (v) For general characterization of rock masses distant from excavation influences, the use of SRF = 5, 2.5, 1.0, and 0.5 is recommended as depth increases from say 0–5, 5–25, 25–250 to >250 m. This will help to adjust Q for some of the effective stress effects, in combination with appropriate characterization values of J_w. Correlations with depth-dependent static deformation modulus and seismic velocity will then follow the practice used when these were developed.

Source: Barton (2002)

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

Source: Barton (2002)

Table 6(iii): Stress Reduction Factor *SRF* (contd...)			
Class	Squeezing rock: plastic flow of incompetent rock under the influence of high rock pressure	σ_θ / σ_c	*SRF*
O	Mild squeezing rock pressure	1 – 5	5 – 10
P	Heavy squeezing rock pressure	> 5	10 -20

Notes: (vi) Cases of squeezing rock may occur for depth, $H > 350\ Q^{1/3}$ according to Singh (1993)*. Rock mass compression strength can be estimated from $\sigma_{cm} \approx 5\gamma Q_c^{1/3}$ (MPa), where γ is the rock density in t/m³, and $Q_c = Q \times \sigma_c/100$, (Barton, 2000)**.

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** Barton, N. 2000. TBM tunneling in jointed and faulted rock. *Rotterdam: Balkema*, 173p.

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

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

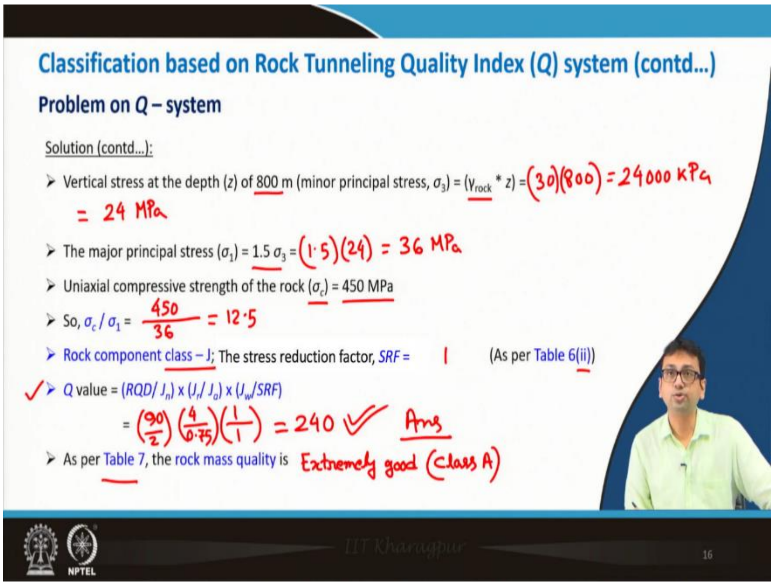
Source: Barton (2002)

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

Table 7: Rock mass classification based on *Q* – system (Barton et al., 1974)

Q - value	Class	Remarks
400 – 1000	A	Exceptionally good
100 – 400	A	Extremely good
40 – 100	A	Very good
10 – 40	B	Good
4 – 10	C	Fair
1 – 4	D	Poor
0.1 – 1.0	E	Very poor
0.01 – 0.1	F	Extremely poor
0.001 – 0.01	G	Exceptionally poor

Source: Deb and Verma (2016)



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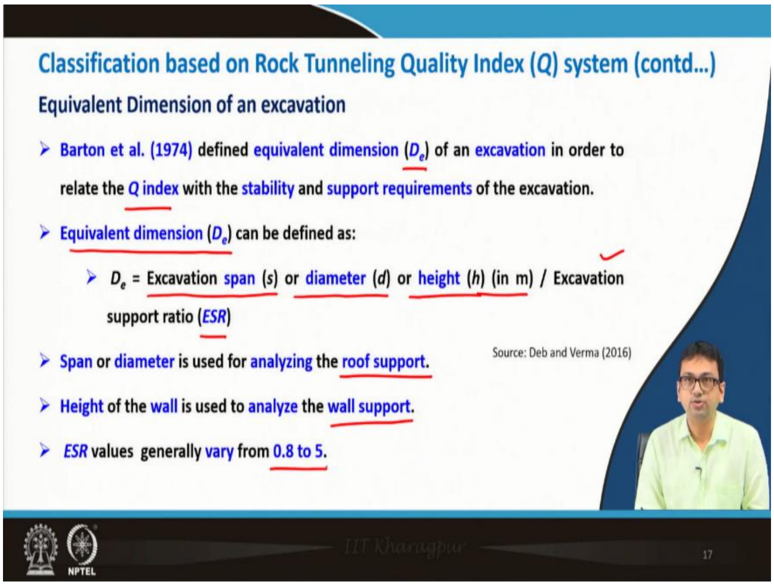

Additionally, Barton et al. 1974 defined equivalent dimension i.e. De of an excavation in order to relate the Q index with the stability and support requirement of the excavation.

Equivalent dimension can be defined as

De = Excavation span (s) or diameter (d) or height (h) (in m) / Excavation support ratio (ESR)

Span or diameter is used for analyzing the roof support, also it is stated that the height of the wall is used to analyze the wall support.

ESR values generally vary from 0.8 to 5. ESR is the excavation support ratio.

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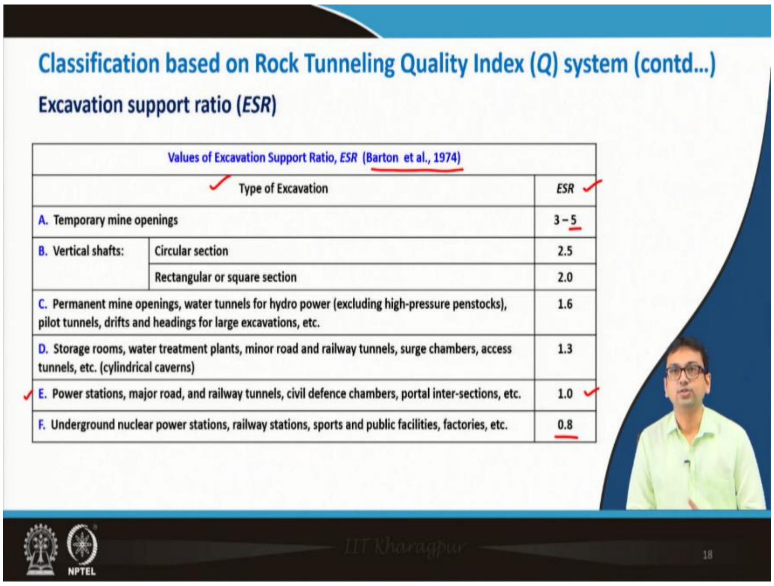

Values of Excavation Support Ratio, *ESR* (Barton et al., 1974)		
Type of Excavation		*ESR*
A. Temporary mine openings		3 – 5
B. Vertical shafts:	Circular section	2.5
	Rectangular or square section	2.0
C. Permanent mine openings, water tunnels for hydro power (excluding high-pressure penstocks), pilot tunnels, drifts and headings for large excavations, etc.		1.6
D. Storage rooms, water treatment plants, minor road and railway tunnels, surge chambers, access tunnels, etc. (cylindrical caverns)		1.3
E. Power stations, major road, and railway tunnels, civil defence chambers, portal inter-sections, etc.		1.0
F. Underground nuclear power stations, railway stations, sports and public facilities, factories, etc.		0.8

For ESR a table is provided by Barton et al. 1974. It gives different classes like A, B, C, D, E, F and different corresponding type of excavations are also written alongwith corresponding ESR values. Like first one is temporary mine opening which has an ESR value between 3 to 5.

On the other hand, if we see the last one that is underground nuclear power station, railway stations, sports and public facilities, factories, etc. for that ESR is 0.8. Likewise for class E, if i.e. the power stations, major road and railway tunnels, civil defence chambers, portal inter-sections, etc. ESR is 1.

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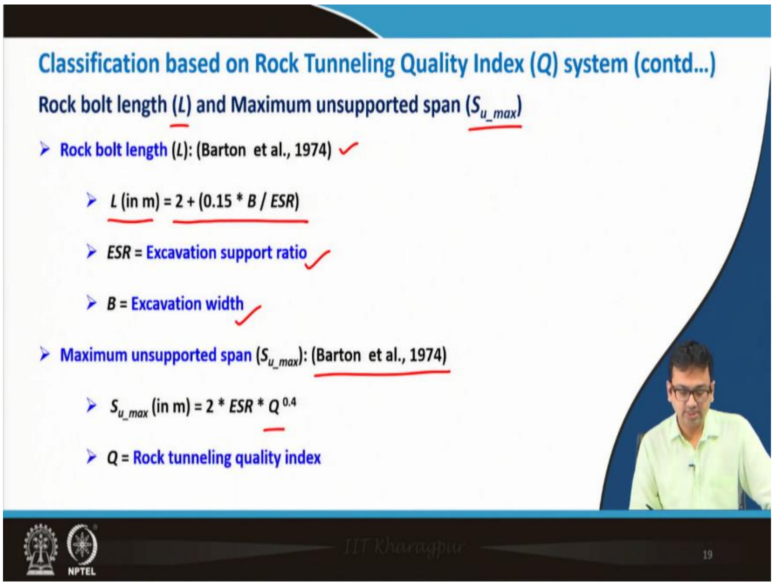

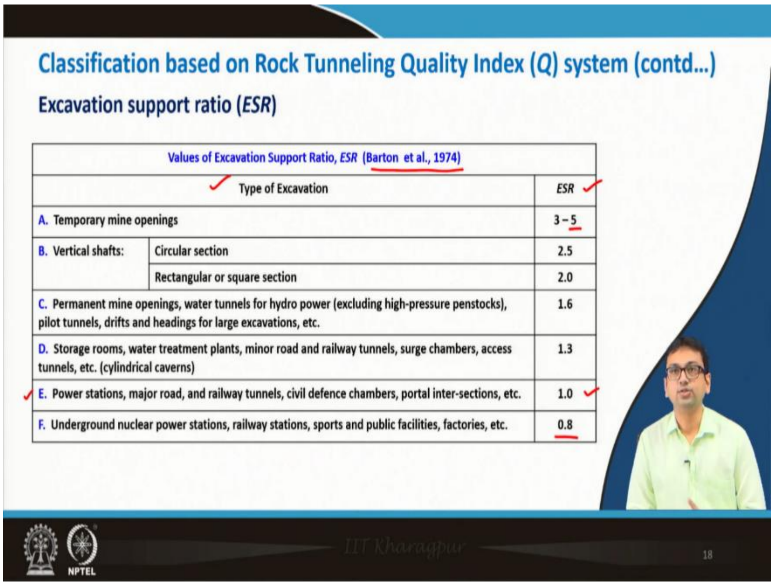

Additional information:

- Rock bolt length (L): (Barton et al., 1974)
    - L (in m) = 2 + (0.15 * B / ESR)
        - ESR = Excavation support ratio (using the table)
        - B = Excavation width
- Maximum unsupported span (S_{u_max}): (Barton et al., 1974)
    - S_{u_max} (in m) = 2 * ESR * Q 0.4
        - Q = Rock tunneling quality index (already calculated)

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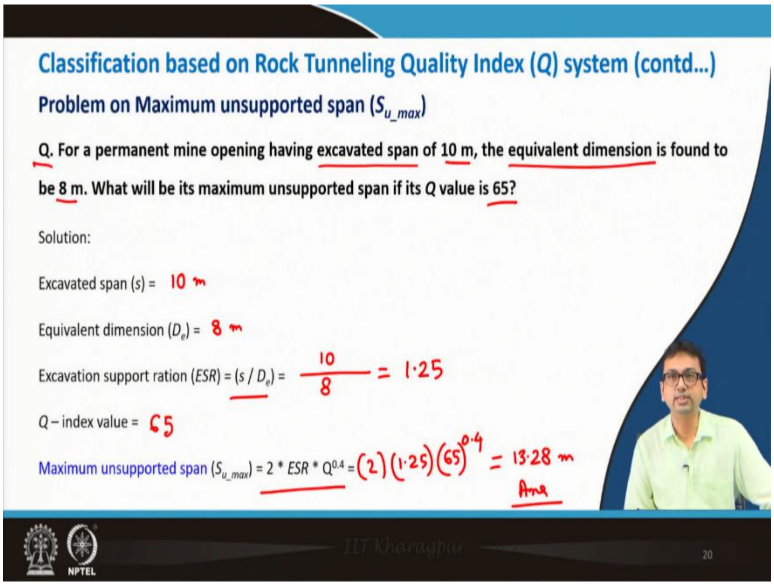
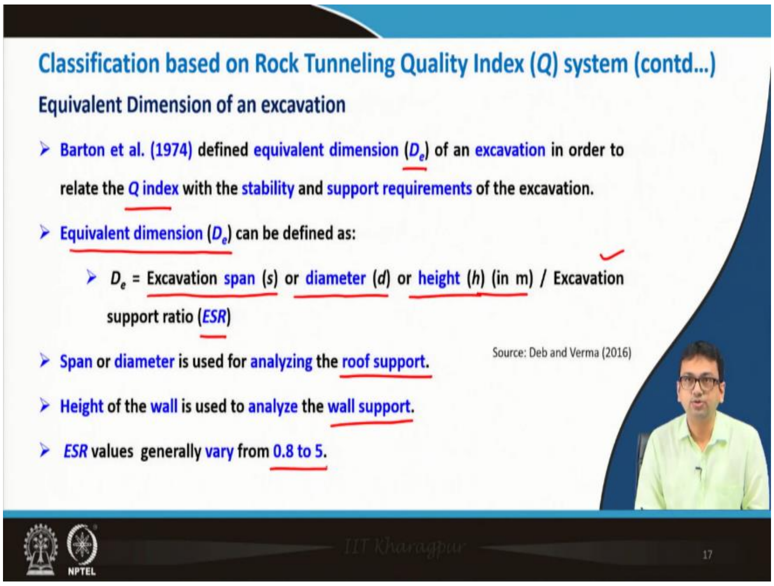




Example problem: For a permanent mine opening having excavation span of 10 m, the equivalent dimension is found to be 8 m. What will be its maximum unsupported span if its Q-value is 65.

Solution:

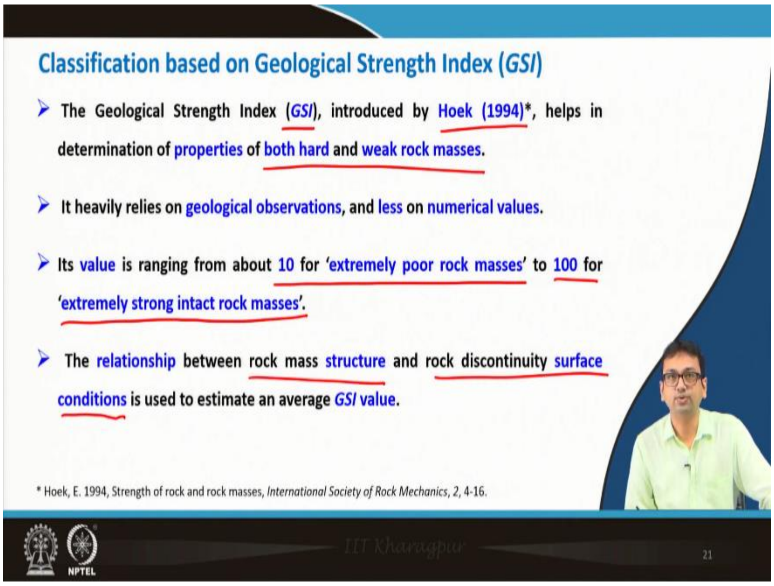
Excavated span (s) = 10 m

Equivalent dimension (De) = 8 m

Excavation support ration (ESR) = (s / De) = 1.25

Q – index value = 65

Maximum unsupported span (S_{u_max}) = 2 * ESR * $Q^{0.4}$ = 13.28 m (Ans)



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Now, we will discuss about the classification based on geological strength index, GSI. It was introduced by Hoek in the year 1994, it helps in determination of properties of both hard and weak rock masses. It heavily relies on the geological observations and less on numerical values. Its value ranges from about 10 for extremely poor rock masses to 100 for extremely strong intact rock masses. The relationship between the rock mass structure and rock discontinuity surface conditions is used to estimate an average GSI value.

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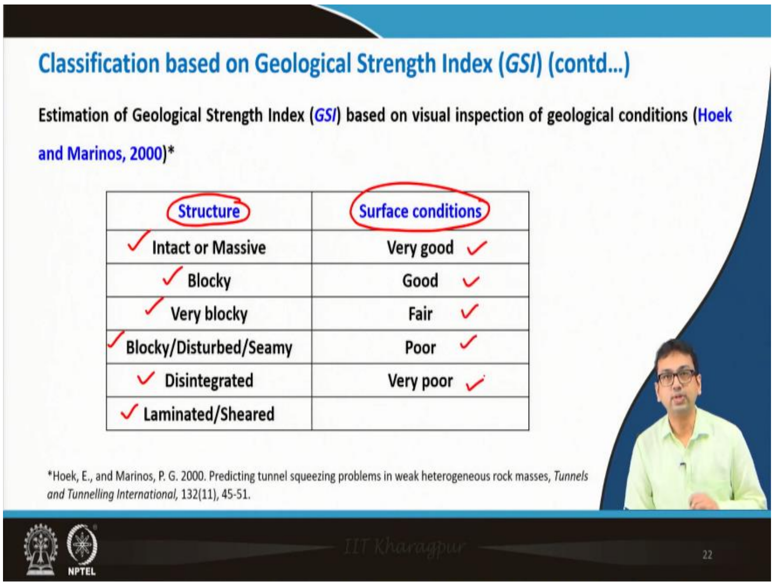

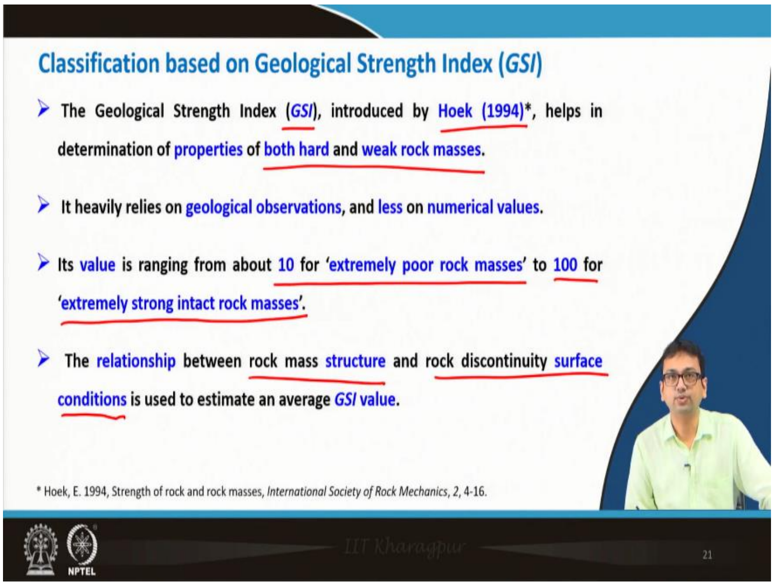

Now, this estimation of geological strength index, GSI is based on visual inspection of geological conditions as per Hoek and Marinos, 2000. There we will notice that two things are there, one is structure, one is surface conditions.

Rock mass structure and surface conditions are two very important parameters for this index. In the table shown in the slide there are different kinds of structures shown with a clear picture and its description as intact or massive, blocky, very blocky, blocky/disturbed/seamy, disintegrated, and laminated/sheared and under surface conditions, they are like very good surface condition, good, fair, poor, very poor.

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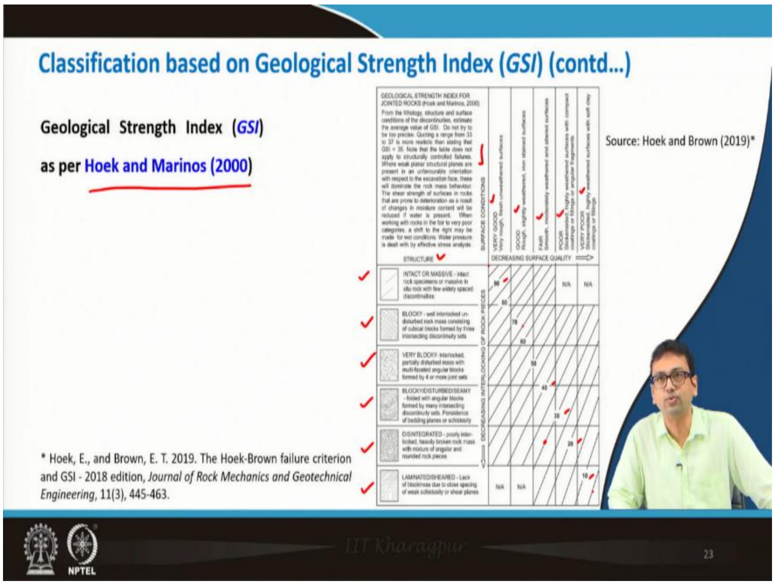

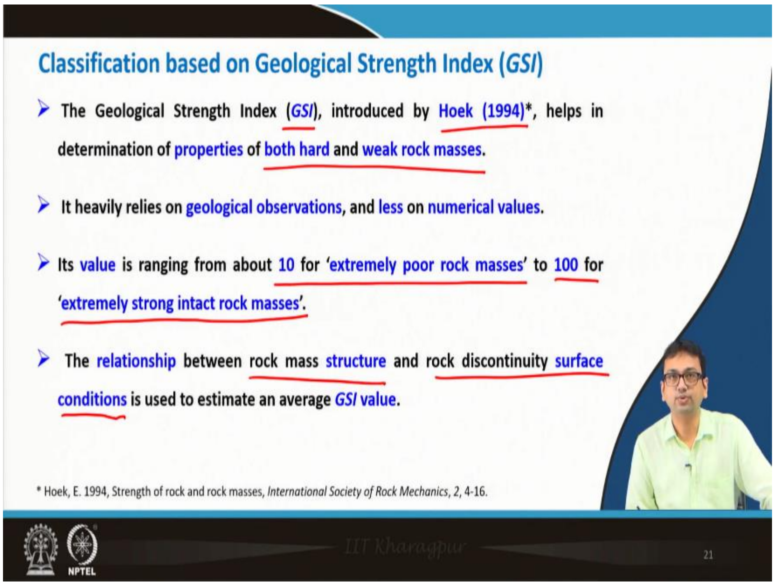

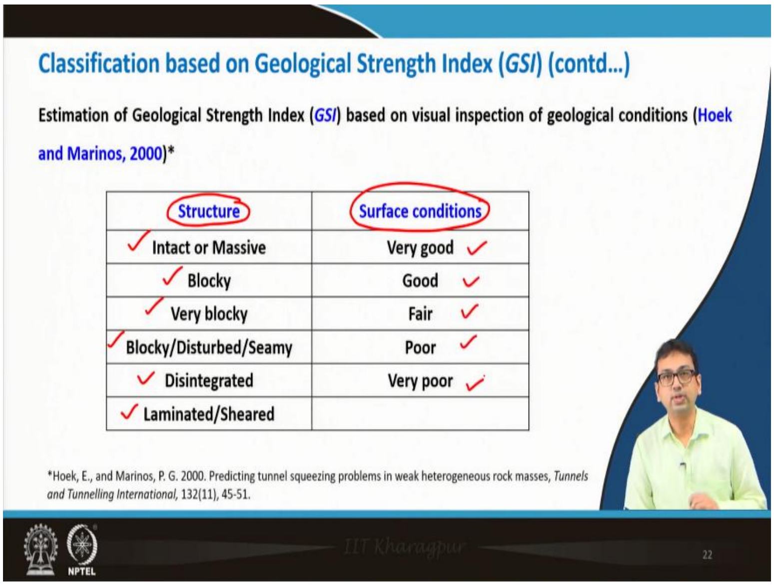

So, now, let us focus on the just this table what is provided by Hoek and Marinos 2000 and let us see what are the things over there as I have stated the structure, structure and the surface conditions and under surface condition, you see very good, good, fair, poor, very poor and under structure as I have mentioned intact rock with the diagram it is shown what does it mean, intact or massive. So, it is also written intact rock specimens or massive in situ rock with few widely spaced discontinuities.

GSI values are given like you see the 10, 20, 30, 40 and so on till 90. As already mentioned GSI varies generally between 10 to 100. For example, suppose structure is blocky and surface condition is good then GSI will be 65.

Also, it is written that quoting a range from like 32 to 37 is more realistic than stating that GSI is exactly 35.

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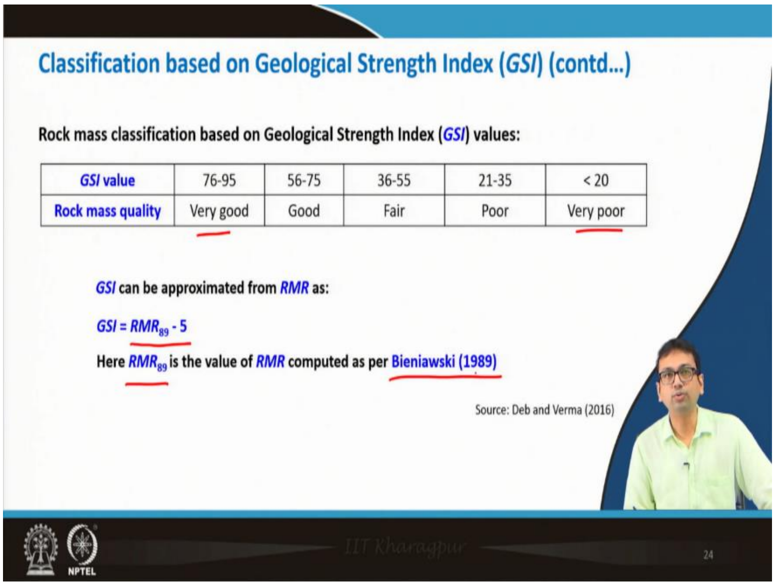

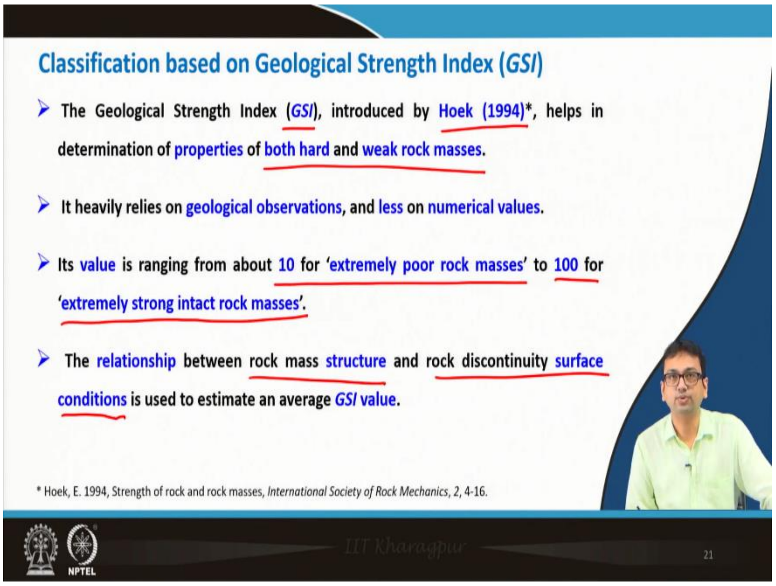

Another table shows rock mass classification based on the GSI. So, it is stating that if the GSI value is like less than 20, it is very poor and 76 to 95 it is very good. So, a GSI value of 100 is for extremely strong intact rock masses.

Now, GSI can be approximately from RMR also.

$$GSI = RMR_{89} - 5$$

RMR_{89} is the value of RMR computed as per Bieniawski (1989). We have learned in detailed about the how to obtain the RMR value as per this tables given by Bieniawski.

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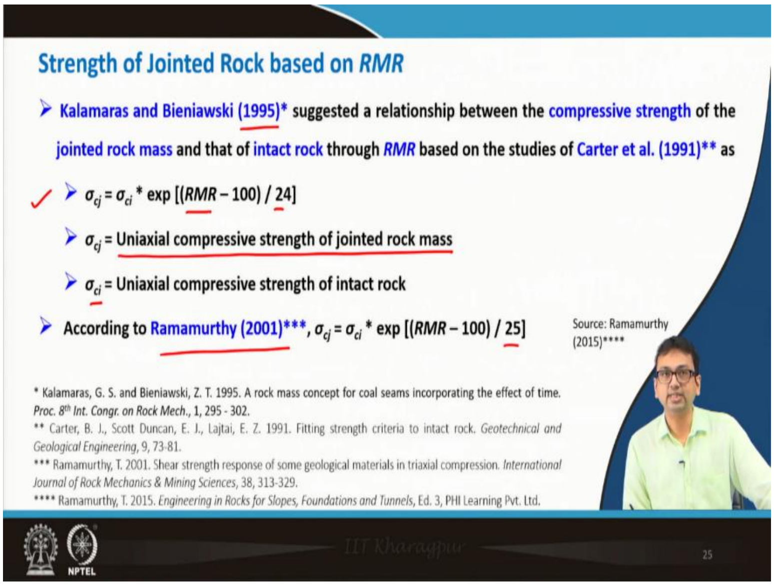

Now, we will discuss about the strength of jointed rock based on RMR. Kalamaras and Bieniawski (1995) suggested a relationship between the compressive strength of the jointed rock mass and that of intact rock through RMR based on the studies of Carter et al. 1991 and the expression is

$$\sigma_{cj} = \sigma_{ci} \times \exp[(RMR - 100)/24]$$

where, σ_{cj} is the uniaxial compressive strength of jointed rock mass and σ_{ci} is the uniaxial compressive strength of intact rock.

According to Ramamurthy (2001)

$$\sigma_{cj} = \sigma_{ci} \times \exp[(RMR - 100)/25]$$

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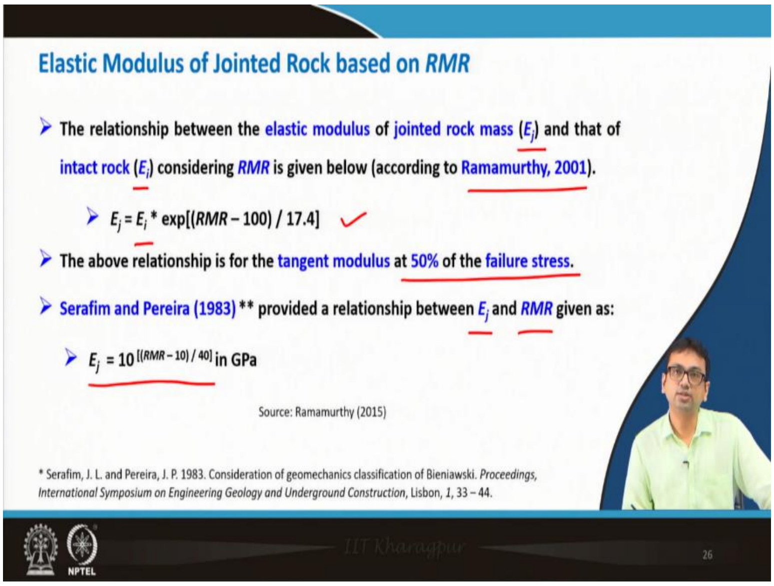

Not only the uniaxial compressive strength, we can also estimate the elastic modulus of jointed rock based on RMR

$E_{cj} = E_{ci} \times \exp[(RMR - 100)/17.4]$ (As per Ramamurthy (2001))

This relationship is between the elastic modulus of jointed rock mass that is E_j and that of the intact rock E_i considering RMR is given. Above relationship is for the tangent modulus at 50% of the failure stress.

Another relationship is given by Serafim and Pereira (1983)

$E_j = 10^{[(RMR-10)/40]}$ IN GPa

It is obvious that RMR can be very useful to obtain not only the strength of jointed rock mass but also the elastic modulus.

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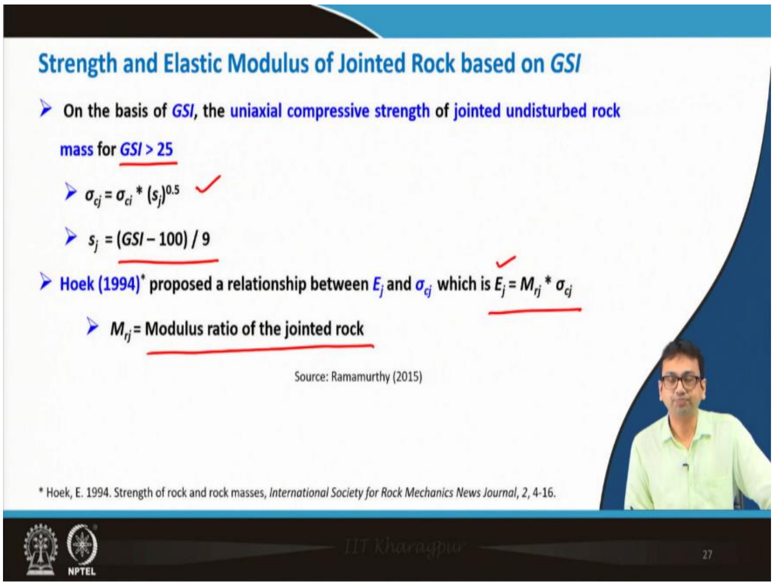

Now similarly, on the basis of GSI the uniaxial compressive strength of jointed undisturbed rock mass for GSI > 25 can be obtain using the following expression.

$$\sigma_{cj} = \sigma_{ci} \times (s_j)^{0.5}$$

$$s_j = (GSI - 100)/9$$

As per Hoek (1994)

$$E_j = M_{rj} \times \sigma_{cj}$$

where M_{rj} is modulus ratio of the jointed rock.

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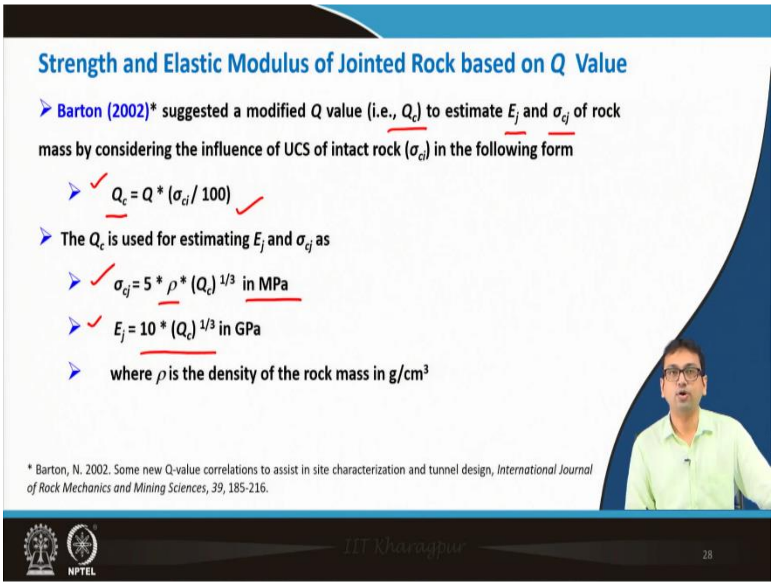

Barton (2002) suggested a modified Q-value i.e., Q_c to estimate this E_j and σ_{cj} of rock mass by considering the influence of UCS of intact rock that is σ_{ci} in the following form

$$Q_c = Q \times (\sigma_{ci}/100)$$

Now, this Q_C is used to estimate σ_{cj} and E_j.

$$\sigma_{cj} = 5 \times \rho \times (Q_c)^{1/3} \text{ in MPa}$$

$$E_j = 10 \times (Q_c)^{1/3} \text{ in GPa}$$

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So, thank you. With this, I am concluding our module 5. So, we will meet again with our module 6 in our next lecture. Thank you.