

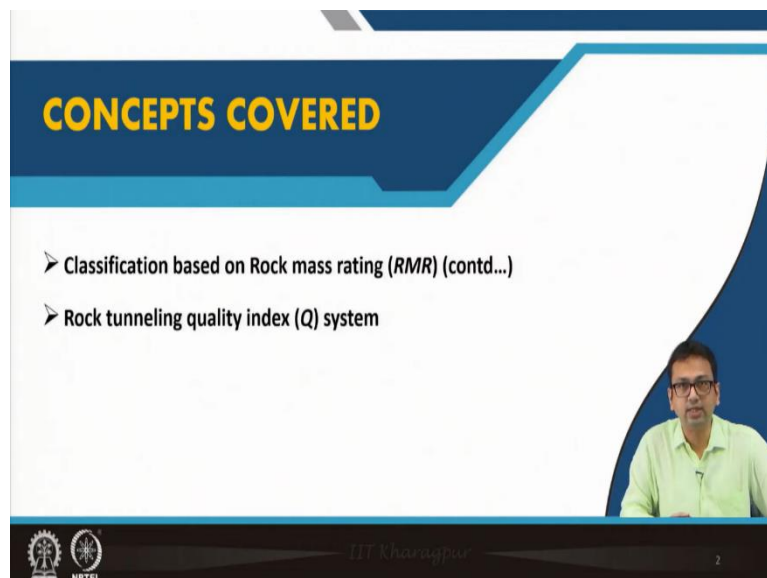
Rock Mechanics and Tunneling
Professor Dr. Debarghya Chakraborty
Department of Civil Engineering
Indian Institute of Technology, Kharagpur
Lecture 25
Rock mass classification (Continued)

(Refer Slide Time: 00:34)



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.

(Refer Slide Time: 01:13)

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)



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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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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
Rating		15	12	7	4	2	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; 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/s)	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	





Dr. K. Srinivasan

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

Source: Bieniawski (1989)

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

Table 2.

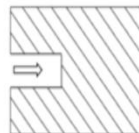
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Classification based on Rock Mass Rating (RMR) (contd...)

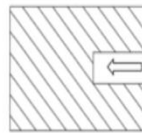
RMR table 3: Effects of discontinuity strike and dip orientation in tunneling

Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip - Dip $45^\circ - 90^\circ$	Drive with dip - Dip $20^\circ - 45^\circ$	Dip $45^\circ - 90^\circ$	Dip $20^\circ - 45^\circ$
Very favourable	Favourable	Very unfavorable	Fair
✓ Drive against dip - Dip $45^\circ - 90^\circ$	Drive against dip - Dip $20^\circ - 45^\circ$	Dip $0^\circ - 20^\circ$ – Irrespective of strike	
Fair	Unfavorable	Fair	

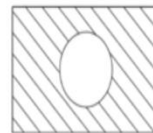
Source:
Bieniawski
(1989)



Drive with dip



Drive against dip



Strike parallel to
tunnel axis



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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)



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

RMR table 4: Rating adjustment for discontinuity orientations (See RMR table 3)

Strike and dip orientations	Very favorable	Favorable	Fair	Unfavorable	Very unfavorable
Tunnels and mines	0	-2	-5	-10	-12
Foundations	0	-2	-7	-15	-25
Slopes	0	-5	-25	-50	

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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 $< 1\text{mm}$)

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

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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)



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

RMR table 1: Classification parameters and their ratings						
Strength of intact rock material	Parameter	Range of values				
	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	5
	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

Source: Bieniawski (1989)



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

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

Source: Bieniawski (1989)



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

✓ Classification parameters	✓ Description	✓ According to RMR table	✓ Rating
Point load strength index			
RQD			
Spacing of discontinuities			
Discontinuity length (Persistence)			
Separation or aperture			
Infilling (gouge)			
Roughness			
Weathering			
Ground water			
Adjustment for discontinuity orientation			
		Total RMR value	

Solution (contd...)



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

✓ Classification parameters	✓ Description	✓ According to RMR table	✓ Rating
Point load strength index	9 MPa	1	12
RQD	60%	1	13
Spacing of discontinuities	0.3m	1	10
✓ Discontinuity length (Persistence)	2.3m	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, Turned	3, 4	-5
		Total RMR value	59

Solution (contd...)

∴ The rock can be considered as 'Fair rock' [As per RMR table]



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

RMR table 4: Rating adjustment for discontinuity orientations (See RMR table 3)

Strike and dip orientations		Very favorable	Favorable	Fair	Unfavorable	Very unfavorable
Ratings	Tunnels and mines	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	

RMR table 5: Rock mass classes determined from total ratings

Rating	100 – 81	80 – 61	60 – 41	40 – 21	< 21
Class number	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

Source: Bieniawski (1989)



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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)



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

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	
	Uniaxial compressive strength (MPa)	>250	100 – 250	50 – 100	25 – 50	For the low range uniaxial compressive strength is preferred
					5 – 25	1 – 5
Rating		15	10	7	4	2
Drill core quality, RQD (%)		90 – 100	75 – 90	50 – 75	25 – 50	< 25
Rating		20	17	10	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	Slackensided surfaces; or Gouge < 5 mm thick; or Separation > 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

Source: Bieniawski (1989)



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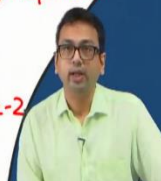
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Classification based on Rock Mass Rating (RMR) (contd...)

- **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 < 1 mm)

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



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

Source: Bieniawski (1989)

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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Classification based on Rock Tunneling Quality Index (Q) system

- The Q-system was developed by Barton et al. (1974)* at the Norwegian Geotechnical Institute, Norway for the determination of rock mass characteristics and tunnel support requirements.
- The numerical value of the index, Q ranges from 0.001 to a maximum of 1,000.

* Barton, N., Lien, R., and Lunde, J. 1974. Engineering classification of rock masses for the design of tunnel support, *Rock Mechanics*, 6, 189-239.

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

➤ Value of Q can be calculated as:

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

➤ RQD = Rock quality designation

➤ J_n = Joint set number (number of discontinuity sets)


➤ J_r = Joint roughness number (roughness of discontinuity surfaces)


➤ J_a = 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 = Stress reduction factor (presence of shear zones, stress concentrations, squeezing or swelling rocks)

Source: Abbas and Konietzky (2017)



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

➤ The first quotient (RQD/J_n) represents the rock mass geometry and is a measure of block size.

✓

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

Note: (i) Where RQD is reported or measured as ≤ 10 (including 0), a nominal value of 10 is used to evaluate Q. (ii) RQD intervals of 5, i.e., 100, 95, 90, etc., are sufficiently accurate.

Source: Barton et al. (1974)

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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

(Refer Slide Time: 27:11)

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

➤ The first quotient (RQD/J_n) (contd...)

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 ✓

Note: (i) For intersections use $(3.0 \times J_n)$ (ii) For portals use $(2.0 \times J_n)$

Source: Barton et al. (1974)

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

- The second quotient (J_r/J_a) is related to inter – block shear strength.
- It represents the roughness and frictional characteristics of the joint walls or filling materials (Singh and Geol, 1999*).

* Singh, B., and Geol, R.K. 1999. Rock mass classification: a practical approach in civil engineering. Amsterdam, Elsevier Science, 282.



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


➤ The second quotient (J_r/J_a) (contd...)

Table 3: Joint Roughness number J_r

Source: Barton et al. (1974)

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 (nominal)
J	Sandy, gravelly or crushed zone thick enough to prevent rock wall contact	1.0 (nominal)

Note: (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, slickensided joints having lineations, provided the lineations are favorably orientated



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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 J_r value is appropriate for you.

(Refer Slide Time: 29:47)

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

➤ The second quotient (J_r/J_a) (contd...)

Table 4: Joint Alteration Number J_a

Class	Joint Alteration Number	ϕ_r (approx.)	J_a
(i) Rock wall contact			
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, mica. Also chlorite, talc, gypsum, graphite, etc., and small quantities of swelling clays. (Discontinuous coatings, 1 - 2 mm or less in thickness)	8 - 16°	4.0

Note: Values of ϕ_r , the residual friction angle, are intended as an approximate guide to the mineralogical properties of the alteration products, if present.

Source: Barton et al. (1974)



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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.

(Refer Slide Time: 30:49)


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

➤ The second quotient (J_r/J_d) (contd...)

Table 4: Joint Alteration Number J_r (contd...)

Class	Joint Alteration Number	ϕ , (approx.)	J_r
(ii) Rock wall contact before 10 cm shear			
F	Sandy particles, clay-free disintegrated rock, etc.	25 - 30°	4
G	Strongly over-consolidated, non-softening clay mineral fillings (continuous, < 5 mm in thickness)	16 - 24°	6
H	Medium or low over-consolidated, softening, clay mineral fillings (continuous, < 5 mm in thickness)	12 - 16°	8
J	Swelling clay fillings, i.e., montmorillonite (continuous, < 5 mm in thickness). Value of J_r 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			
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 clay conditions)	6 - 24°	10, 13 or 13 - 20

Source: Barton et al. (1974)




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(Refer Slide Time: 31:25)

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

➤ The third quotient (J_w/SRF) represents the concept of **active stress** incorporating water pressures and flows, the presence of shear zones and clay bearing rocks, squeezing and swelling rocks and in situ stress state (Hoek, 2007).



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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.

(Refer Slide Time: 31:51)

Classification based on Rock Tunneling Quality Index (Q) system (contd...)
 ➤ The third quotient (J_w/SRF) (contd...)

Table 5: Joint water reduction factor J_w

Source: Barton et al. (1974)

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

Note: (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.

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.

(Refer Slide Time: 32:42)

Classification based on Rock Tunneling Quality Index (Q) system (contd...)
 ➤ The third quotient (J_w/SRF) (contd...)

Table 6(i): Stress Reduction Factor SRF

Source: Barton et al. (1974)

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

Note: (i) Reduce these values SRF by 25-50% if the relevant shear zones only influence but do not intersect the excavation.

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 $\frac{\sigma_c}{\sigma_1}$ and $\frac{\sigma_t}{\sigma_1}$ where σ_1 and

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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 (U_p/SRF) (contd...)

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

Class	Competent rock, rock stress problems	σ_2 / σ_1	σ_3 / 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

Source: Barton et al. (1974)

Note: (ii) For strongly anisotropic stress field (if measured): when $5 \leq \sigma_2 / \sigma_3 \leq 10$, reduce σ_2 to $0.8\sigma_2$ and σ_3 to $0.8\sigma_3$; when $\sigma_2 / \sigma_3 > 10$, reduce σ_2 to $0.6\sigma_2$ and σ_3 to $0.6\sigma_3$; 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).



(Refer Slide Time: 34:00)

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

➤ The third quotient (U_w/SRF) (contd...)

Table 6(iii): Stress Reduction Factor SRF (contd...) Source: Barton et al. (1974)

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

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

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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.

(Refer Slide Time: 34:22)

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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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.


(Refer Slide Time: 35:16)

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

- Barton (2002)* little modified the tables.
- RMR can be approximated from Q value by:
 - ✓ $RMR \approx 9 \ln Q + 44$ Bieniawski (1989) ✓
 - ✓ $RMR \approx 15 \log Q + 50$ Barton (1995)** ✓

Source: Deb and Verma (2016)

*Barton, N. 2002. Some new Q-value correlations to assist in site characterization and tunnel design. *International Journal of Rock Mechanics and Mining Sciences*, 39(2), 185–216.
 **Barton, N. 1995. The influence of joint properties in modelling jointed rock masses. In 8th ISRM Congress. *International Society for Rock Mechanics and Rock Engineering*, 1023-1032.



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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.

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

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

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


(Refer Slide Time: 36:51)

Modified tables for Q system according to Barton (2002)

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 $(3.0 \times J_n)$. (ii) For portals use $(2.0 \times J_n)$



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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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Modified tables for Q system according to 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, slickensided joints having lineations, provided the lineations are orientated for 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 $\tau \approx \sigma_n \tan^2(J_r/J_a)$).

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Modified tables for Q system according to 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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(Refer Slide Time: 37:52)

Modified tables for Q system according to Barton (2002)

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_w 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.



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Modified tables for Q system according to Barton (2002)

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.



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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 $\frac{\sigma_\theta}{\sigma_c}$ where σ_θ is nothing but the maximum tangential stress. Also, a new class S was added in table 6(iv).

(Refer Slide Time: 38:08)

Modified tables for Q system according to Barton (2002)

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

Class	Competent rock, rock stress problems	σ_1 / σ_3	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_1 to $0.75\sigma_1$; When $\sigma_1 / \sigma_3 > 10$, reduce σ_1 to $0.5\sigma_1$; where σ_1 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_r 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_r . Correlations with depth-dependent static deformation modulus and seismic velocity will then follow the practice used when these were developed.



(Refer Slide Time: 38:12)

Modified tables for Q system according to 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/m^3 , and $Q_c = Q \times \sigma_c / 100$, (Barton, 2000)**.

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

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



(Refer Slide Time: 38:16)

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



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

➤ The third quotient (U_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



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

➤ The third quotient (U_w/SRF) (contd...)

Table 6(ii): Stress Reduction Factor SRF (contd...)				
Class	Competent rock, rock stress problems	σ_1 / σ_3	σ_1 / σ_3	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_3 to $0.8\sigma_3$ and σ_1 to $0.8\sigma_1$; when $\sigma_1 / \sigma_3 > 10$, reduce σ_3 to $0.6\sigma_3$ and σ_1 to $0.6\sigma_1$; where σ_3 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)



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(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.