

Rock Mechanics and Tunneling
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Lecture 22
Rock mass classification

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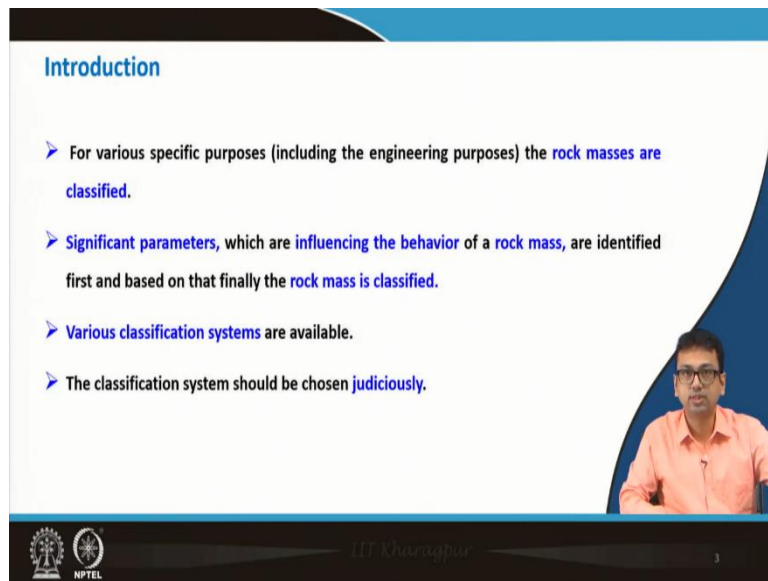
Hello everyone. I welcome all of you to the first lecture of module 5. In module 5, we will discuss the Rock Mass Classification. So, let us begin.

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So, in today's lecture, we will start with a brief introduction then we will discuss briefly intact rock and rock mass and then discontinuities. Under that our focus will be to learn about the factors affecting discontinuities.

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Introduction

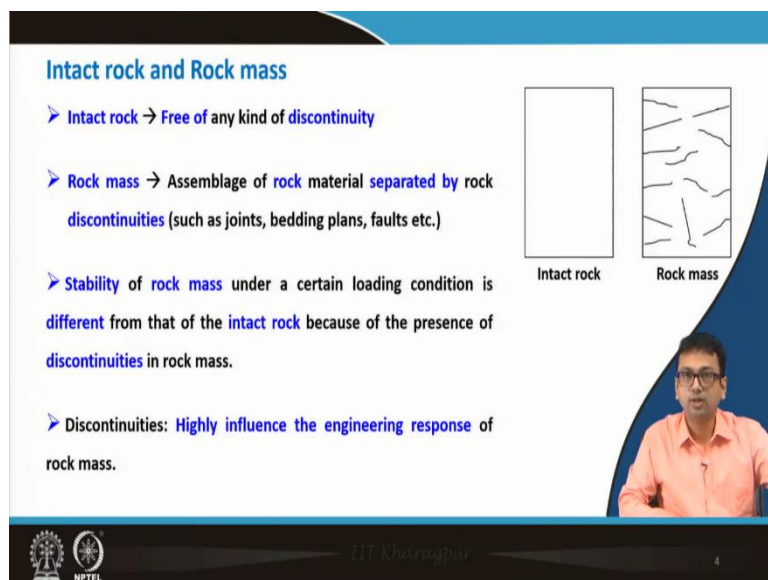
- For various specific purposes (including the engineering purposes) the **rock masses are classified**.
- **Significant parameters**, which are **influencing the behavior** of a **rock mass**, are identified first and based on that finally the **rock mass is classified**.
- **Various classification systems** are available.
- The classification system should be chosen **judiciously**.

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Now, for various specific purposes including the engineering purposes in which we are interested, rock masses are classified. Significant parameters which are influencing the behaviour of a rock mass are identified first and based on that finally, the rock mass is classified.

There are various classification systems available and they are developed for serving a particular purpose. So, the classification system should be chosen judiciously.

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Intact rock and Rock mass

- **Intact rock** → Free of any kind of **discontinuity**
- **Rock mass** → Assemblage of **rock material separated by rock discontinuities** (such as joints, bedding planes, faults etc.)
- **Stability** of **rock mass** under a certain loading condition is **different** from that of the **intact rock** because of the presence of **discontinuities** in rock mass.
- **Discontinuities**: **Highly influence the engineering response** of rock mass.

Intact rock Rock mass

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We know what is the intact rock. It is free of any kind of discontinuities. Whereas, the rock mass is an assemblage of rock materials separated by rock discontinuities such as joints, bedding planes, faults, etc. We have discussed this in detail. We also know that the stability

of rock mass under certain loading conditions is different from that of the intact rock because of the presence of discontinuities in the rock mass. I have stated earlier that discontinuities highly influence the engineering response of the rock mass that we know.

(Refer Slide Time: 03:01)

The slide is titled "Factors affecting discontinuities" in blue text. A red handwritten note "1962" is next to the title. Below the title, a blue arrow points to the text: "International Society for Rock Mechanics (ISRM) → 'Suggested methods for quantitative description of discontinuities in rock masses' → Ten important parameters (ISRM, 1978*):". A red bracket groups the following list of parameters:

- Orientation
- Spacing
- Persistence
- Roughness
- Wall strength
- Aperture
- Filling
- Seepage
- Number of joint sets
- Block size and shape

At the bottom right of the slide, there is a small video inset of a man in an orange shirt. Below the list of parameters, there is a small footnote: "* International Society for Rock Mechanics commission on standardization of laboratory and field tests. 1978. Int. J. Rock Mech. Sci. & Geomech. Abstr. 15, 319 - 368". The slide also features the IIT Kharagpur and NPTEL logos at the bottom left and the text "IIT Kharagpur" at the bottom center.

So, now with this much background, I can discuss the factors affecting the discontinuities because in our subsequent class we will find that these factors (terms) will come again and again. So, in this first lecture only we will try to understand or learn about these specific terms, and what do they mean. The International Society for Rock Mechanics that is ISRM has suggested methods for quantitative description of discontinuities in the rock mass and for that purpose, they have given 10 important parameters.

It must be mentioned that ISRM was found in the year 1962. Now, let us focus on the 10 important parameters. First one is orientation, second one is spacing, third persistence, fourth roughness, fifth wall strength followed by aperture being sixth, then seventh filling, eighth seepage, ninth number of joint sets and last (tenth) block size and shape.

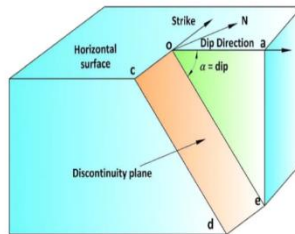
We will now learn about these 10 parameters recommended by ISRM on 1978 which actually affect the discontinuities and ultimately the strength of the rock mass depends highly on these discontinuities.

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Factors affecting discontinuities (contd...)

Orientation

➤ ATTITUDE: Strike, Dip direction, Dip



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So, first let us start with the orientation. Regarding orientation, we have discussed in detail. So, we know what attitude is, it is the combination of strike, dip direction and dip and with the help of these terms, we can tell about the orientation of the discontinuity plane that we know.

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Factors affecting discontinuities (contd...)

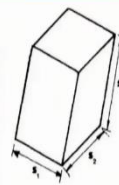
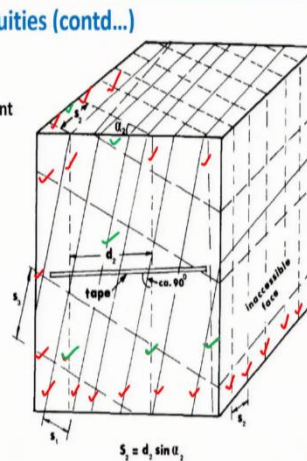
Spacing

➤ Normal distance between adjacent discontinuities.

$$S_2 = d_2 \sin \alpha_2$$

- set no. 1 ✓
- - - set no. 2 ✓
- set no. 3 ✓

Source: ISRM (1978)



Dr. Khuram

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So, let us discuss the next parameter which is the spacing. So, what is spacing? It is nothing but the normal distance between adjacent discontinuities. Now we also know that a group of parallel joints are called joint sets and several such joint sets intersect to form a joint system. Now here, we are focusing on the spacing and it is stated that it is the normal distance between adjacent discontinuity.

So, now let us see the discontinuities present here. We can see a pattern of parallel joints in the slide. There are three joint sets as is visible in the slide.

Spacing has been calculated for joint set 2 i.e. S_2 .

$$S_2 = d_2 \sin \alpha_2$$

Where d_2 and α_2 are shown in the slide.

Similarly,

$$S_1 = d_1 \sin \alpha_1$$

$$S_3 = d_3 \sin \alpha_3$$

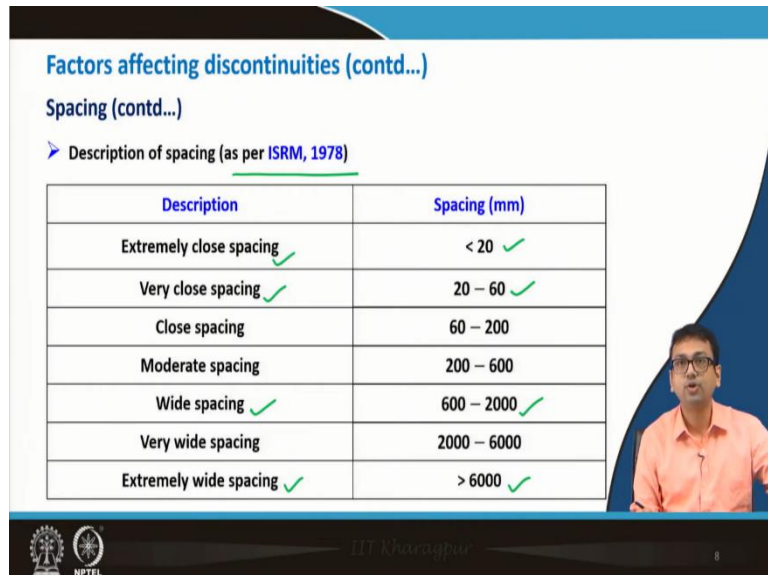
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Factors affecting discontinuities (contd...)

Spacing (contd...)

➤ Description of spacing (as per ISRM, 1978)

Description	Spacing (mm)
Extremely close spacing ✓	< 20 ✓
Very close spacing ✓	20 – 60 ✓
Close spacing	60 – 200
Moderate spacing	200 – 600
Wide spacing ✓	600 – 2000 ✓
Very wide spacing	2000 – 6000
Extremely wide spacing ✓	> 6000 ✓



Based on spacing, ISRM has given additional information i.e. if the spacing is less than 20 millimetres, then it can be described as extremely close spacing and if more than 600 millimetres means 6 meter then extremely wide spacing. So, obviously very less spacing is not desirable.

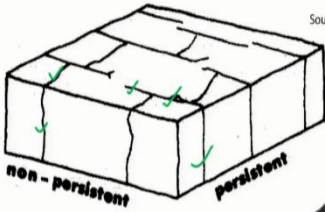
You can see if it is 20 to 60 mm it is very close spacing. Likewise, 600 metre to 2000 metre means 2 metre, so, it is wide spacing. Likewise, extremely wide spacing greater than 6 metre, so we can see this way this is given by ISRM.

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Factors affecting discontinuities (contd...)

Persistence

- The areal extent or size of a discontinuity within a plane.
- It can be crudely quantified by observing the discontinuity trace lengths on the surface of exposures.
- Discontinuities of one particular set will often be more continuous than those of the other sets.



Source: ISRM (1978)

non-persistent persistent

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Now, another term is persistence. It is the areal extent or size of a discontinuity within a plane. It can be crudely quantified by observing the discontinuity trace length on the surface of exposure. The discontinuities of one particular set will often be more continuous than those of the others.

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Factors affecting discontinuities (contd...)

Persistence (contd...)

- Description of persistence (as per ISRM, 1978)

Description	Trace length (m)
Very low persistence	< 1
Low persistence	1 – 3
Medium persistence	3 – 10
High persistence	10 – 20
Very high persistence	> 20

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ISRM has given some description of persistence also. It says, if the trace length is less than 1 metre, very low persistence. Likewise, 1 to 3 low persistence and greater than 20 metre then very high persistence.

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Factors affecting discontinuities (contd...)
Roughness

- Wall roughness of a discontinuity is a potentially important component of its shear strength, especially in the case of undisplaced and interlocked features (e.g. unfilled joints).
- Roughness of discontinuity wall can be characterized
 - Waviness – large scale surface undulations observed over several meters
 - It can be called stepped, undulating or planar.
 - Unevenness – small scale roughness of the two sides relative to the mean plane, observed over several centimeters
 - It can be called rough, smooth or slickensided.



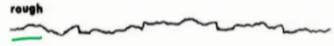
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Another parameter is roughness. So, wall roughness of a discontinuity is a potentially important component of its shear strength especially, in the case of undisplaced and interlocked features, for example, unfilled joints. Now roughness of the discontinuity wall can be characterized by waviness and unevenness.

Waviness is the large-scale surface undulations observed over several meters also called stepped or undulating or planar. Unevenness is the small-scale roughness of the two sides relative to the mean plane observed over several centimetres. It can be called rough, smooth or slickensided.

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Factors affecting discontinuities (contd...)
Roughness (contd...)

- Combining the waviness and unevenness, the roughness of joint can be classified as follows:
 - I – Rough, stepped

 - II – Smooth, stepped

 - III – Slickensided, stepped


Source: ISRM (1978)



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So, refer to slides, combining the waviness and unevenness, the roughness of joints can be classified as follows, this is as per ISRM 1978 only. First is rough and stepped, second is smooth and stepped, third is slickensided and stepped.

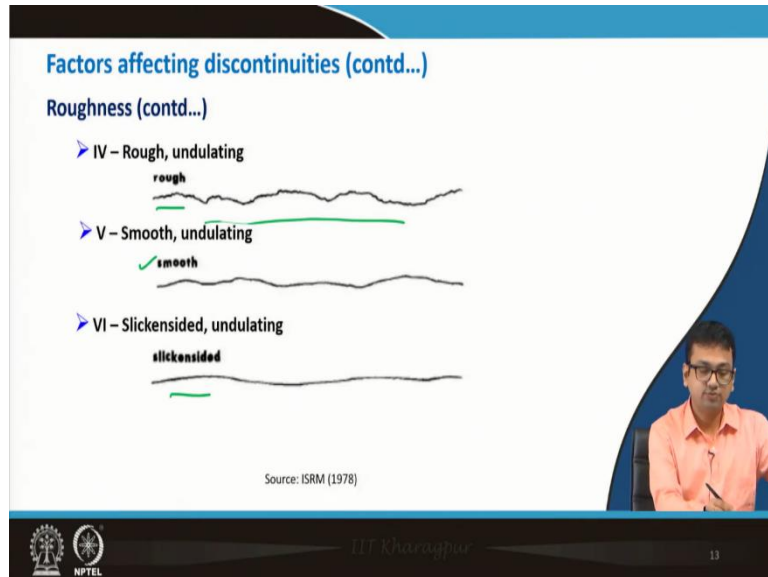
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Factors affecting discontinuities (contd...)

Roughness (contd...)

- IV – Rough, undulating
rough
- V – Smooth, undulating
smooth
- VI – Slickensided, undulating
slickensided

Source: ISRM (1978)



The slide displays three joint surface profiles. The first, labeled 'IV – Rough, undulating', shows a highly irregular, wavy line with a green checkmark and the word 'rough' written above it. The second, labeled 'V – Smooth, undulating', shows a smoother, wavy line with a green checkmark and the word 'smooth' written above it. The third, labeled 'VI – Slickensided, undulating', shows a smooth, wavy line with a green checkmark and the word 'slickensided' written above it. The slide is part of a presentation from IIT Kharagpur, NPTEL, as indicated by the logos and text at the bottom.

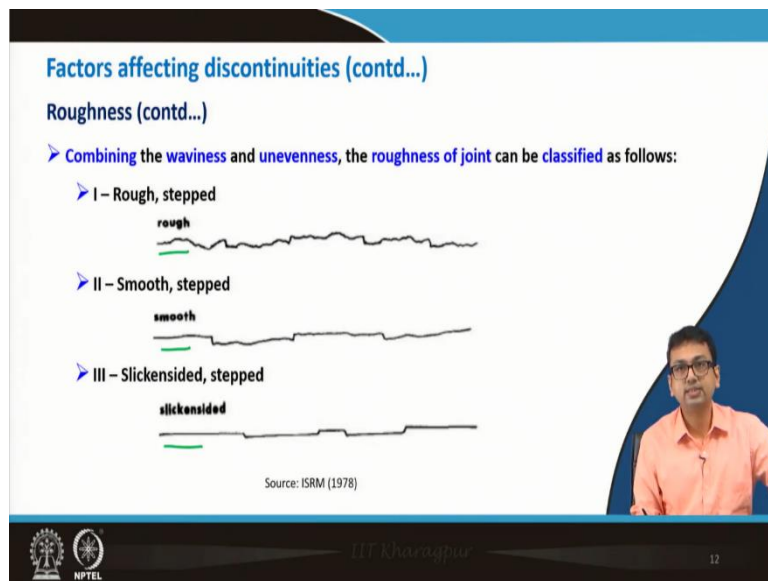
Factors affecting discontinuities (contd...)

Roughness (contd...)

➤ Combining the waviness and unevenness, the roughness of joint can be classified as follows:

- I – Rough, stepped
rough
- II – Smooth, stepped
smooth
- III – Slickensided, stepped
slickensided

Source: ISRM (1978)



The slide displays three joint surface profiles. The first, labeled 'I – Rough, stepped', shows a line with sharp, irregular steps and a green checkmark and the word 'rough' written above it. The second, labeled 'II – Smooth, stepped', shows a line with smooth, regular steps and a green checkmark and the word 'smooth' written above it. The third, labeled 'III – Slickensided, stepped', shows a line with smooth, regular steps and a green checkmark and the word 'slickensided' written above it. The slide is part of a presentation from IIT Kharagpur, NPTEL, as indicated by the logos and text at the bottom.

Fourth, fifth and sixth are rough undulating, smooth undulating and slickensided undulating patterns.

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Factors affecting discontinuities (contd...)

Roughness (contd...)

- VII – Rough, planar

- VIII – Smooth, planar

- IX – Slickensided, planar


Source: ISRM (1978)

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Seventh is rough planar, eighth is smooth planar and last one is slickensided planar.

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Factors affecting discontinuities (contd...)

Roughness (contd...)

Roughness classification		
Class	Waviness and unevenness	Joint roughness number, J_r
I ✓	Rough, stepped ✓	4 ✓
II	Smooth, stepped ✓	3 ✓
III	Slickensided, stepped ✓	2
IV	Rough, undulating	3
V	Smooth, undulating	2
VI	Slickensided, undulating	1.5
VII	Rough, planar	1.5
VIII	Smooth, planar	1
IX ✓	Slickensided, planar	0.5 ✓

Source: Sivakugan et al. (2013)

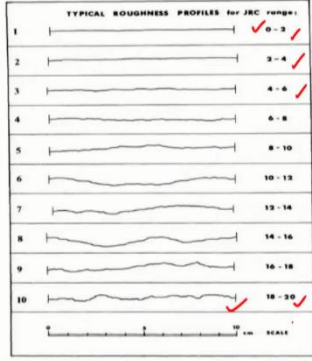
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Therefore, based on waviness and unevenness, discontinuities can be classified.

Now, J_r , joint roughness number. For rough stepped is 4 and then smooth stepped is 3 likewise, when you go to the last one, that is slickensided planar it becomes 0.5. So, this is one of the important table which gives us the idea about the roughness based on the waviness and unevenness.

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Factors affecting discontinuities (contd...)
Roughness (contd...)



Typical Roughness Profiles for JRC ranges:

Profile	JRC Range
1	0 - 2
2	2 - 4
3	4 - 6
4	6 - 8
5	8 - 10
6	10 - 12
7	12 - 14
8	14 - 16
9	16 - 18
10	18 - 20

Source: ISRM (1978)

* Barton N. 1973. Review of a new shear strength criterion for rock joints. *Engng Geol.* 7, 287 - 332.

➤ Barton (1973)* quantified roughness by 'joint roughness coefficient' (JRC) ranges from 0 - 20.

Factors affecting discontinuities (contd...)
Roughness (contd...)

Roughness classification		
Class	Waviness and unevenness	Joint roughness number, J_r
I	Rough, stepped	4
II	Smooth, stepped	3
III	Slickensided, stepped	2
IV	Rough, undulating	3
V	Smooth, undulating	2
VI	Slickensided, undulating	1.5
VII	Rough, planar	1.5
VIII	Smooth, planar	1
IX	Slickensided, planar	0.5

Source: Sivakugan et al. (2013)

Barton in 1973 quantified roughness by joint roughness coefficient JRC. In future you may see this term we are using, joint roughness coefficient JRC. Its range is from 0 to 20 and it is graded as per the roughness. You can find this in ISRM 1978 only.

You can see 0 is for very smooth and almost planar and the grade increases with increase in roughness.

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Factors affecting discontinuities (contd...)

Wall strength

- An equivalent **compressive strength** of the adjacent **rock walls** of a discontinuity.
- **Barton (1973)** defined **wall strength** by a term called 'joint wall compressive strength' (**JCS**).
- **Franklin and Dusseault (1989)*** evaluated the **relationship** between **JCS** and **Schmidt hammer rebound number (R)**, which is given below:

✓ $\log_{10}(JCS) = 0.00088\gamma R + 1.01$

where, γ is the unit weight of rock in kN/m^3 .

* Franklin J. A., and Dusseault M. 1989. *Rock Engineering*. McGraw-Hill

Handwritten notes:
R varied between 10 - 60
Here 10 indicates 'Weak'
Rock $G_c < 20 \text{ MPa}$

Wall strength is another important parameter that affects the discontinuity. It is an equivalent compressive strength of the adjacent rock walls of a discontinuity. Barton 1973 defined wall strength by a term called joint wall compressive strength JCS.

And Franklin and Dusseault 1989 evaluated the relationship between JCS and Schmidt hammer rebound number (R) as $\log_{10}(JCS) = 0.00088\gamma R + 1.01$. Where γ is unit weight of rock in kN/m^3 .

Schmidt hammer rebound number R in practical case varies between 10 to 60. Now, 10 indicates the weak rock, so this here like 10 indicates weak rock having the uniaxial compressive strength less than 20 Mega Pascal.

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Factors affecting discontinuities (contd...)
Estimation of shear strength based on roughness and wall strength

➤ The main objective in describing the roughness and strength of walls of discontinuities is to estimate the shear strength of unfilled discontinuities (in particular).

➤ $\tau = \sigma_n' \tan(\phi + i)$

➤ τ = shear strength (peak or residual)

➤ ϕ = friction angle (peak, ϕ_{peak} or residual, ϕ_r)

➤ σ_n' = effective normal stress

➤ i = waviness

Open or unfilled discontinuity
 Source: Sivakugan et al. (2013)

Source: ISRM (1978)

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So, now estimation of shear strength based on roughness and wall strength. The main objective in describing the roughness and strength of walls of discontinuities is to estimate the shear strength of unfilled discontinuities particularly.

So, now if tau is the shear strength, then as we know sigma n dash tan. Now here, phi plus i this is coming over here, so tau is shear strength as we know it may be peak or residual, we are familiar with these two terms. In your previous module also, we have discussed about this peak and residual.

$$\tau = \sigma_n' \tan(\phi + i)$$

Where τ is shear strength (peak or residual), ϕ is friction angle (peak or residual), σ_n' is effective normal stress and i is waviness.

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Factors affecting discontinuities (contd...)

Estimation of shear strength based on roughness and wall strength (contd...)

- The roughness angle or waviness (i) can be estimated as:
 - $i = JRC * \log_{10}(JCS / \sigma_n')$
 - JRC = Joint roughness coefficient ✓
 - JCS = Joint wall compression strength ✓
- $\varphi_{peak} = JRC * \log_{10}(JCS / \sigma_n') + \varphi_r$



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Factors affecting discontinuities (contd...)

Wall strength

- An equivalent compressive strength of the adjacent rock walls of a discontinuity.
- Barton (1973) defined wall strength by a term called 'joint wall compressive strength' (JCS).
- Franklin and Dusseault (1989)* evaluated the relationship between JCS and Schmidt hammer rebound number (R), which is given below:
 - ✓ $\log_{10}(JCS) = 0.00088\gamma R + 1.01$ ✓
 - where, γ is the unit weight of rock in kN/m^3 .

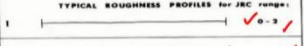
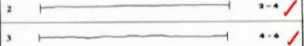
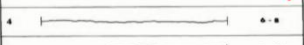
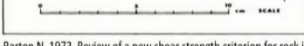
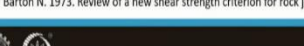
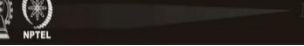
*R varied between 10 – 60
Hence 10 indicates 'Weak'
Rock $G_c < 20$ MPa*



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Factors affecting discontinuities (contd...)

Roughness (contd...)

TYPICAL ROUGHNESS PROFILES for JRC range:		
1		0 - 3 ✓
2		3 - 4 ✓
3		4 - 6 ✓
4		6 - 8
5		8 - 10
6		10 - 13
7		13 - 16
8		16 - 18
9		18 - 20
10		20 - 24 ✓

Source: ISRM (1978)

- Barton (1973)* quantified roughness by 'joint roughness coefficient' (JRC) ranges from 0 – 20.



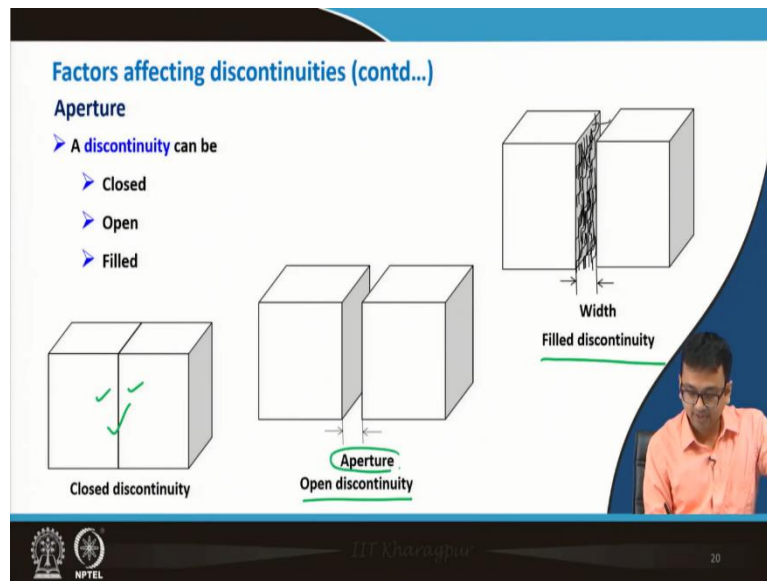
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Now, the roughness angle or waviness, so that is a new term can be estimated as $i = JRC * \log_{10}(JCS / \sigma_n')$ where JRC and JCS joint wall compressive strength and joint roughness coefficient respectively.

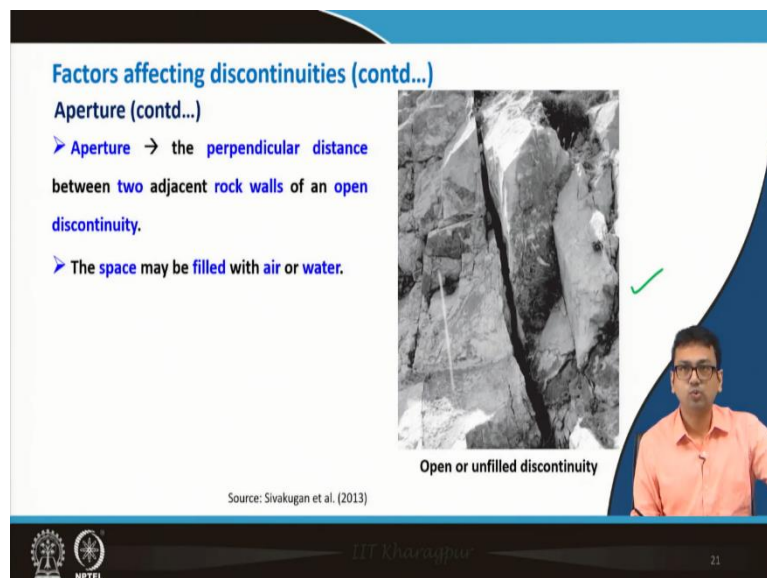
To find ϕ_{peak} if we know ϕ_r , the equation is as follows

$$\phi_{peak} = JRC * \log_{10}(JCS / \sigma_n') + \phi_r$$

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(Refer Slide Time: 25:51)



Aperture is the perpendicular distance between two adjacent rock walls of an open discontinuity. The space (if present) may be filled with air or water.

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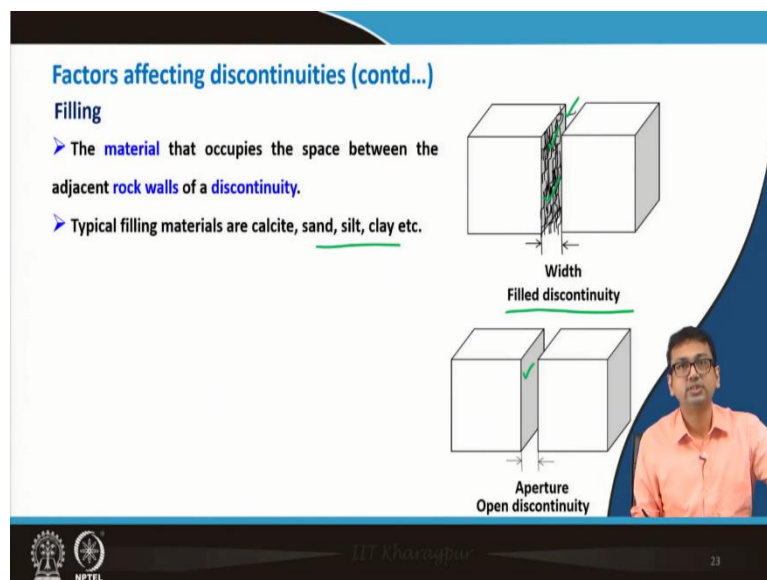
Factors affecting discontinuities (contd...)
Aperture (contd...)

Description associated with aperture (ISRM, 1978)		
	Description	Aperture (mm)
Closed feature	Very tight ✓	< 0.1 ✓
	Tight	0.1 – 0.25
	Partly open	0.25 – 0.5
Gapped feature	Open ✓	200 – 2.5 ✓
	Moderately wide	600 – 10
	Wide	> 10
Open feature	Very wide ✓	10 – 100 ✓
	Extremely wide	100 – 1000
	Cavernous	> 1000



Now, based on this aperture, ISRM has given some descriptions like if it is very tight, then the aperture must be less than 0.1 millimetres likewise if it is open then 200 to 2.5 millimetres aperture. Likewise, if it is very wide then 10 to 100 millimetres aperture. So, this is again a useful table and we may find its utilization later.

(Refer Slide Time: 26:54)



Now we will discuss filling. The material that occupies the space between the adjacent rock walls of a discontinuity is nothing but the filling. Now, typical filling materials are sand, silt, clay, calcite, etc.

Refer to slides and you can see the filled discontinuity and you see that these are the filling materials whereas, in the case of aperture, it was an open discontinuity. So, we have to

understand that filling means the presence of filling material in open discontinuities and it is very important as far as the strength of the rock mass is concerned.

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Factors affecting discontinuities (contd...)

Seepage

- Water seepage through rock masses results from flow through the discontinuities.
- The rate of seepage is proportional to the local hydraulic gradient.
- Seepage from unfilled or filled discontinuities or from tunnel wall or in a surface exposure, can be assessed as per 'seepage rating'.

Source: ISRM (1978)

Now, another term is seepage, it also affects the performance of the discontinuity. The water seepage through rock masses results in flow through the discontinuities. The rate of seepage is proportional to the local hydraulic gradient.

Seepage from unfilled or filled discontinuities or tunnel walls or in surface exposure can be assessed as per the 'seepage rating'. ISRM has given three quite useful tables.

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Factors affecting discontinuities (contd...)

Seepage rating

Unfilled discontinuities	
Seepage rating	Description
✓ I	The discontinuity is very tight and dry, water flow along it is not possible
✓ II	The discontinuity is dry with no evidence of water flow
III	The discontinuity is dry but shows evidence of water flow (i.e. rust straining etc.)
IV	The discontinuity is damp but no free water is present
V	The discontinuity shows seepage, occasional drops of water, but no continuous flow
✓ VI	The discontinuity shows a <u>continuous flow of water</u>

Source: ISRM (1978)

Let us see what is there. The first seepage rating is for unfilled discontinuities. Seepage ratings are given by 1, 2 likewise up to 6, 1 indicates discontinuity is very tight and dry, water

flow along it is not possible. Likewise, if we see the sixth one, the discontinuity shows a continuous flow of water.

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Factors affecting discontinuities (contd...)
Seepage rating (contd...)

Filled discontinuities	
Seepage rating	Description
I ✓	The filling materials are heavily consolidated, dry and <u>very low permeable</u>
II	The filling materials are damp, but no free water is present
III	The filling materials are wet, occasional drops of water
IV	The filling materials show signs of outwash, continuous flow of water
V	The filling materials are washed out locally, considerable water flow along the out – wash channels
VI ✓	<u>The filling materials are washed out completely, very high water pressure experienced</u>

Source: ISRM (1978)

Similarly, for filled discontinuity there are similar ratings from 1 to 6, we can see 1 indicates the filling materials are heavily consolidated, dry and very low permeable. And if it is stated the seepage rating is 6 for filled discontinuity, we can say that the filling materials are washed out completely very high-water pressure experienced.

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Factors affecting discontinuities (contd...)
Seepage rating (contd...)

Tunnel wall	
Seepage rating	Description
I ✓	<u>Dry walls and roof, no detectable seepage</u>
II	Minor seepage, specify dripping discontinuities
III	Medium inflow, specify discontinuities with continuous flow
IV	Major inflow, specify discontinuities with strong flows
V ✓	Exceptionally high inflow, specify source of exceptional flows

Source: ISRM (1978)

Likewise, the third one is related to the tunnel. For tunnel walls also ISRM in 1978 gave some guidelines like seepage rating from 1 to 5. 1 indicates dry wall and roof no detectable seepage. Second one is minor seepage, specify dripping discontinuities.

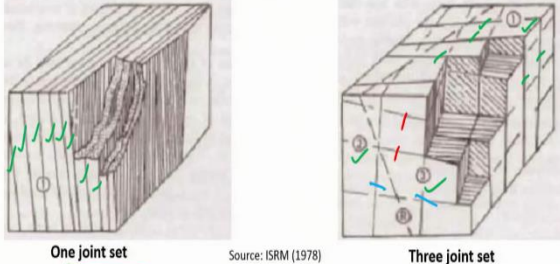
Likewise, fifth one is exceptionally high inflow, specify source of exceptional.

(Refer Slide Time: 30:50)

Factors affecting discontinuities (contd...)

Number of joint sets

- Number of joint sets in the discontinuity system is one of the influential factors used in classifying the rock mass.
- Due to the increase in number of joint sets, the individual block size decreases.



One joint set Source: ISRM (1978) Three joint set

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Now, next one is number of joint sets. So, regarding joint set we have already discussed while discussing the spacing. Number of joint sets in the discontinuity system is one of the influential factor used in classifying the rock mass. So, due to the increase in number of joint set the individual block size decreases obviously. Now in the first diagram in slide, we can see there is only one joint set because a group of parallel joints follow one type of pattern only. Second figure has three joint sets.

(Refer Slide Time: 32:13)

Factors affecting discontinuities (contd...)

Number of joint sets (contd...)

Classification based on number of joint sets	
Description	Joint sets
I ✓	Massive, occasional random joints ✓
II	One joint set ✓
III ✓	One joint set plus random ✓
IV ✓	Two joint sets ✓
V	Two joint sets plus random
VI	Three joint sets
VII	Three joint sets plus random
VIII	Four or more joint sets
IX ✓	Crushed rock, similar to soil

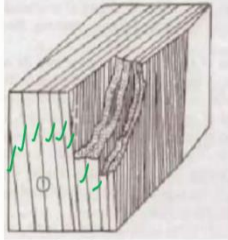
Source: ISRM (1978)

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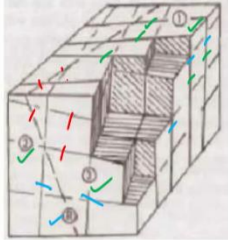
Factors affecting discontinuities (contd...)

Number of joint sets

- Number of joint sets in the discontinuity system is one of the influential factors used in classifying the rock mass.
- Due to the increase in number of joint sets, the individual block size decreases.



One joint set



Three joint set

Source: ISRM (1978)



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ISRM has given some classification based on the number of joint sets also. So, here description from 1 to 9. If it is 1, it is a massive and occasional random joint. So, random joint means as you can see in the slide, r is written, there is only one particular line and no parallel line is following its pattern.

2 is the one joint set, then likewise one joint set plus random that is for 3. Then two joint sets that is 4 likewise, you can see if you look at the table a lot of new information is there which can be useful for classification because this is a classification based on the number of joint sets.

(Refer Slide Time: 33:41)

Factors affecting discontinuities (contd...)

Block size

- Block size is determined using the discontinuity orientation, spacing, number of joint sets, and the persistence.
- The number of joint sets and the orientation determine the shape of the resulting blocks (the shape of the blocks may be cubes, tetrahedrons, sheets etc.)
- Block size can be described by
 - Block size index, $I_b \rightarrow$ Average dimension of typical blocks
 - Volumetric joint count, $J_v \rightarrow$ Total number of joints intersecting a unit volume of rock mass

Source: ISRM (1978)



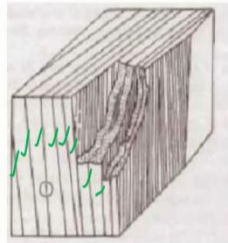
30

Factors affecting discontinuities (contd...)

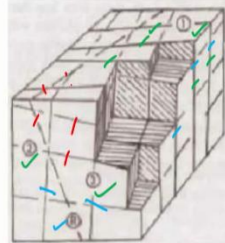
Number of joint sets

➤ Number of joint sets in the discontinuity system is one of the influential factors used in classifying the rock mass.

➤ Due to the increase in number of joint sets, the individual block size decreases.



Source: ISRM (1978)



Three joint set



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Next is block size. So, block size is very much related to the joint set as I have stated just couple of slides back that due to the increase in the number of joint sets the individual block size decreases obviously. Now block size is determined using discontinuity orientation, spacing, number of joint sets and persistence. The number of joint sets and the orientation determines the shape of the resulting blocks, the shapes of these blocks may be cubes it may be tetrahedrons, it may be sheets, etc.

So, again block size can be described by two things. One is block size index I_b , it is nothing but the average dimension of typical blocks and the other is volumetric joint count J_v which is very important. The volumetric joint count is nothing but the total number of joints intersecting a unit volume of the rock mass. The total number of joints intersecting a unit volume of the rock mass.

(Refer Slide Time: 35:06)

Factors affecting discontinuities (contd...)
Block size (contd...)

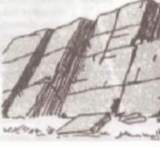
Blocky



Irregular



Tabular



columnar



Source: ISRM (1978)





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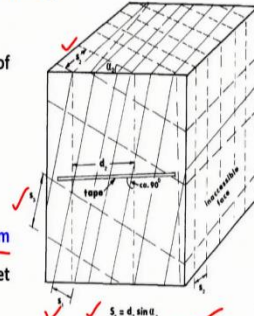
(Refer Slide Time: 35:32)

Factors affecting discontinuities (contd...)
Block size (contd...)

- **Block size Index (I_b)**: For the joint system of three joint sets (as shown in the figure)

$$I_b = (S_1 + S_2 + S_3) / 3$$
- **Volumetric joint count (J_v)**: Defined as the sum of number of joints per meter for each joint set present (ISRM, 1978).

$$J_v = (1/S_1 + 1/S_2 + \dots + 1/S_n)$$



Source: ISRM (1978)

$$J_v = \frac{1}{S_1} + \frac{1}{S_2} + \frac{1}{S_3}$$





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Now, refer to the diagram in the slide which we have already discussed while discussing spacing. We have calculated S_1 , S_2 and S_3 using d_1 , d_2 and d_3 and α_1 , α_2 and α_3 . So, I_b can be calculated as $I_b = (S_1 + S_2 + S_3)/3$.

Now, as stated volumetric joint count very important. So, it is defined as the sum of number of joints per metre for each joint set present, so each joint must be considered. So, in slides there are 3 joint sets. J_v can be calculated as $J_v = (1/S_1 + 1/S_2 + \dots + 1/S_n)$

(Refer Slide Time: 37:18)

Factors affecting discontinuities (contd...)
Block size (contd...)

- ISRM (1978) suggested the relationship between the RQD and J_v as:
 - $RQD = 115 - 3.3J_v$
 - $RQD = 100$ for $J_v < 4.5$



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J_v is important because ISRM 1978 suggests the relationship between the RQD and J_v . RQD, is rock quality designation. So, RQD as per ISRM 1978 can be obtained using this J_v

$$RQD = 115 - 3.3J_v$$

$$RQD = 100 \text{ for } J_v < 4.5$$

(Refer Slide Time: 38:07)

Factors affecting discontinuities (contd...)
Block size (contd...)

➤ Q. A rock mass consists of five joint sets. The joint counts are normal to each sets as 15 per 12 m for joint set 1, 10 per 8 m for joint set 2, 7 per 5 m for joint set 3, 16 per 20 m for joint set 4, and 12 per 16 m for joint set 5. Find the J_v . How the block size is described? (Deb and Verma, 2016*)

Solution: The joint spacing are $s_1 = 12/15$; $s_2 = 8/10$; $s_3 = 5/7$, $s_4 = 20/16$ and $s_5 = 16/12$.

Volumetric joint count (J_v) = $(1/s_1 + 1/s_2 + 1/s_3 + 1/s_4 + 1/s_5) = (15/12 + 10/8 + 7/5 + 16/20 + 12/16) = 5.45 (> 4.5)$ Ans

The value of $RQD = (115 - 3.3J_v) = (115 - 3.3 \times 5.45) = 97\%$ (Rock quality – Very Good)

* Deb, D., and Verma A. K. 2016. *Fundamentals and applications of rock mechanics*. PHI Learning Pvt. Ltd.



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Now, let us take a small problem and with this we will conclude. So, you see a small problem that will clear out your doubt regarding J_v .

It says a rock mass consists of five joint sets, The joint counts are normal to each set as 15 per 12 metre for joint set 1, 10 per 8 metre for joint set 2, 7 per 5 meter for joint set 3, 16 per 20 meters for joint set 4 and 12 per 16 meters for joint set 5.

Solution:

The joint spacing are $S_1 = \frac{12}{15}$, $S_2 = \frac{8}{10}$, $S_3 = \frac{5}{7}$, $S_4 = \frac{20}{16}$, $S_5 = \frac{16}{12}$

Volumetric Joint count $J_v = \frac{1}{S_1} + \frac{1}{S_2} + \frac{1}{S_3} + \frac{1}{S_4} + \frac{1}{S_5} = \frac{15}{12} + \frac{10}{8} + \frac{7}{5} + \frac{16}{20} + \frac{12}{16} = 5.45 > 4.5$

The value of $RQD = 115 - 3.3J_v = 115 - 3.3 \times 5.54 = 97\%$ (Rock quality-Very good)



So, thank you. Let us stop here for our today's lecture. We have discussed about different factors affecting discontinuities and from our next lecture, we will directly start discussing about different rock mass classification systems and we will see that these terms that we have discussed today will be used again and again when we discuss about the rock mass classification systems. Thank you.