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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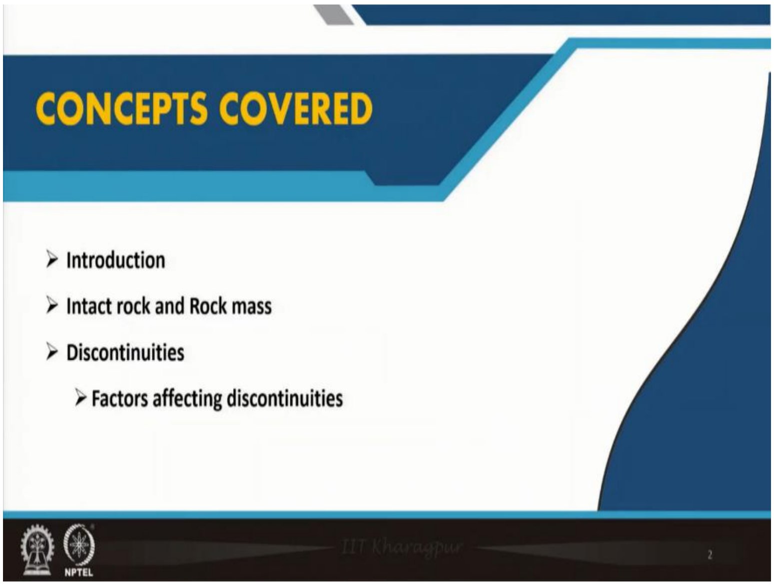

So, in today's lecture, we will start with a brief introduction then we will discuss briefly intact rock and rock mass and then discontinuities. Under that our focus will be to learn about the factors affecting discontinuities.

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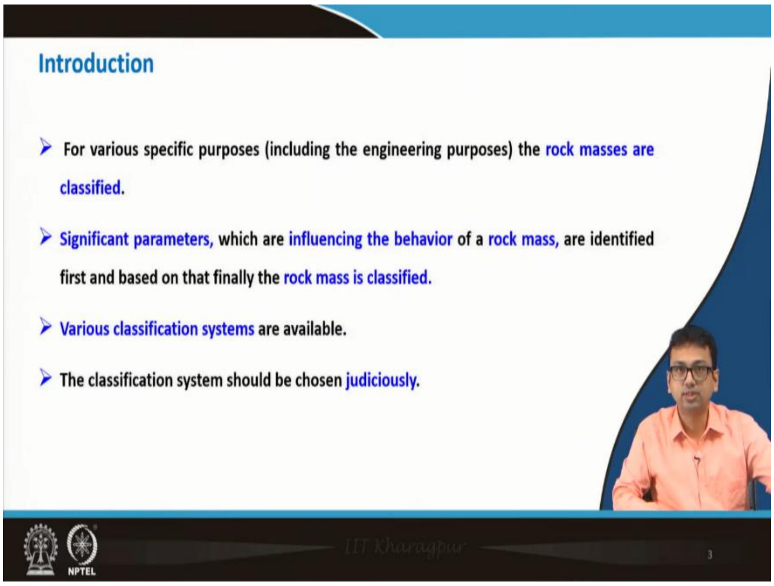

Now, for various specific purposes including the engineering purposes in which we are interested, rock masses are classified. Significant parameters which are influencing the behaviour of a rock mass are identified first and based on that finally, the rock mass is classified.

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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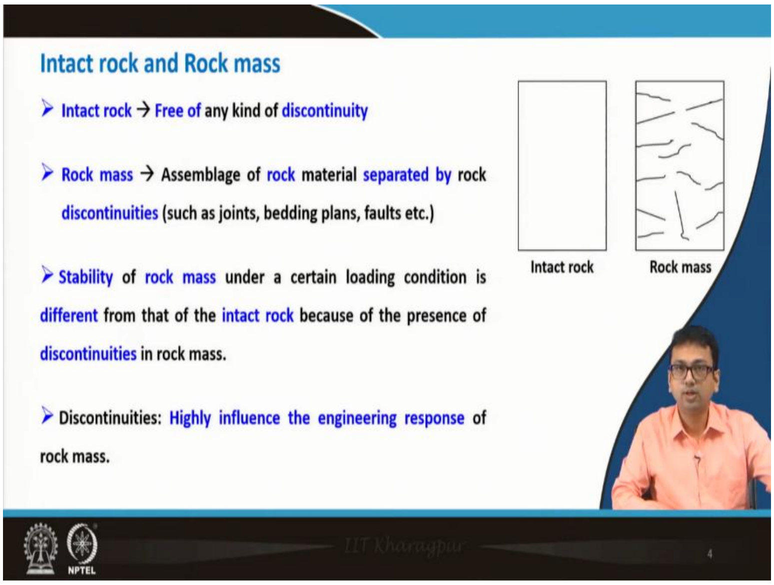

We know what is the intact rock. It is free of any kind of discontinuities. Whereas, the rock mass is an assemblage of rock materials separated by rock discontinuities such as joints, bedding planes, faults, etc. We have discussed this in detail. We also know that the stability of rock mass under certain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

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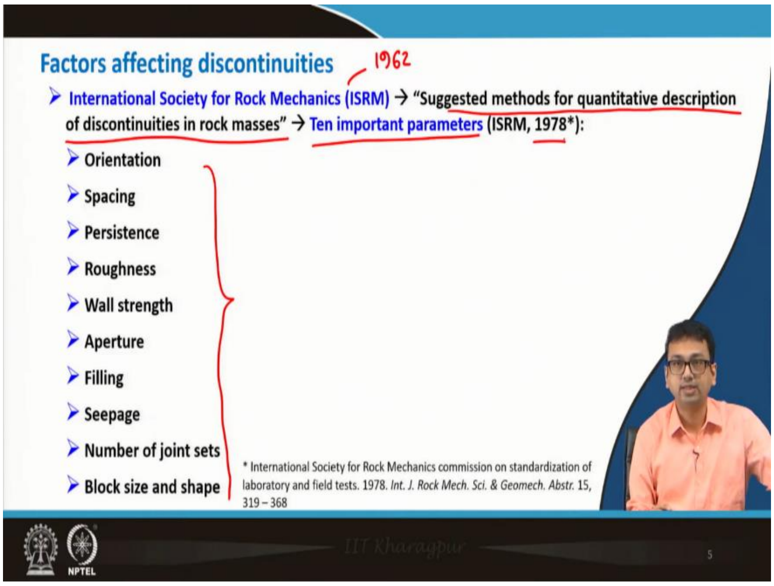

So, now with this much background, I can discuss the factors affecting the discontinuities because in our subsequent class we will find that these factors (terms) will come again and again. So, in this first lecture only we will try to understand or learn about these specific terms, and what do they 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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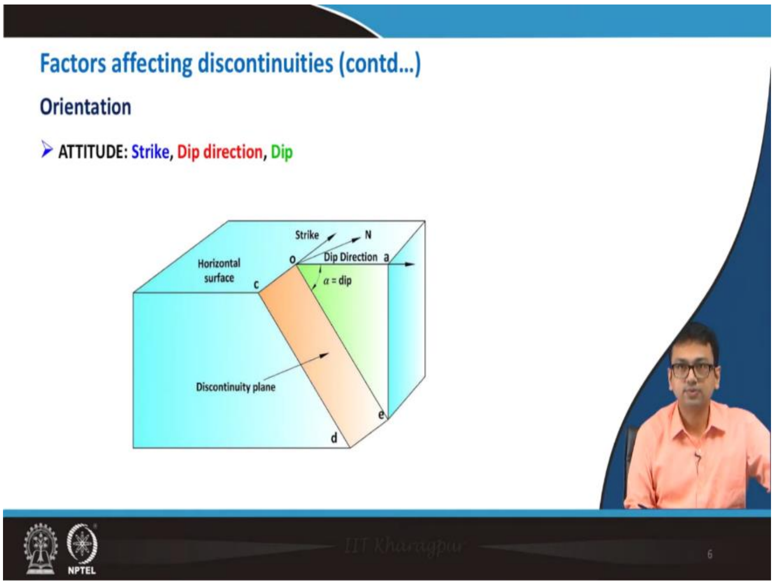

So, first let us start with the orientation. Regarding orientation, we have discussed in detail. So, we know what attitude is, it is the combination of strike, dip direction and dip and with the help of these terms, we can tell about the orientation of the discontinuity plane that we know.

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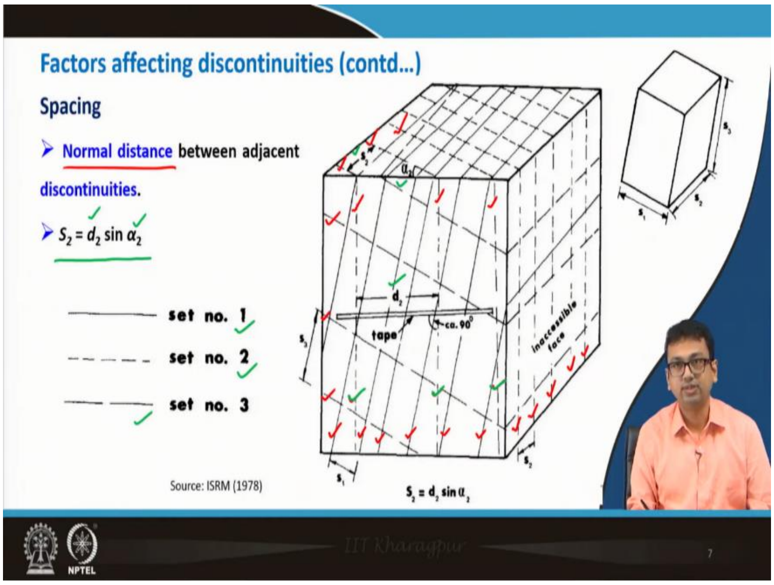

So, let us discuss the next parameter which is the spacing. So, what is spacing? It is nothing but the normal distance between adjacent discontinuities. Now we also know that a group of parallel joints are called joint sets and several such joint sets intersect to form a joint system. Now here, we are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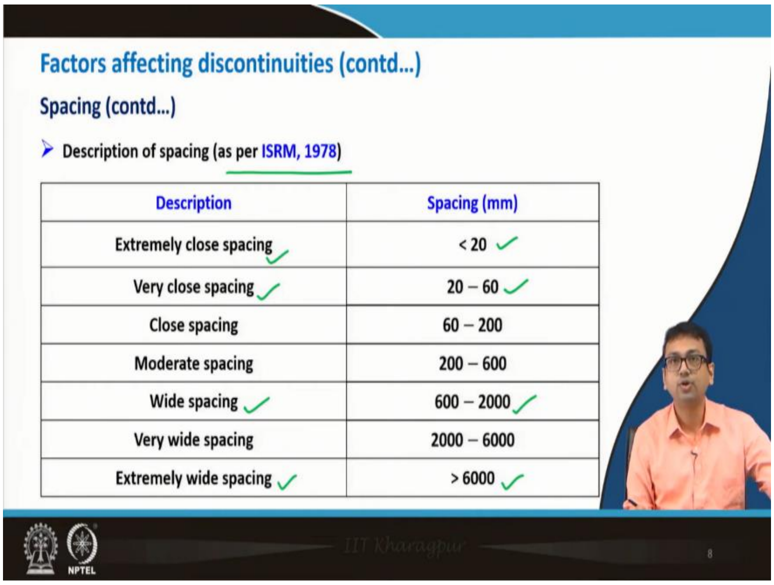

Based on spacing, ISRM has given additional information i.e. if the spacing is less than 20 millimetres, then it can be described as extremely close spacing and if more than 600 millimetres means 6 meter then extremely wide spacing. So, obviously very less spacing is not desirable.

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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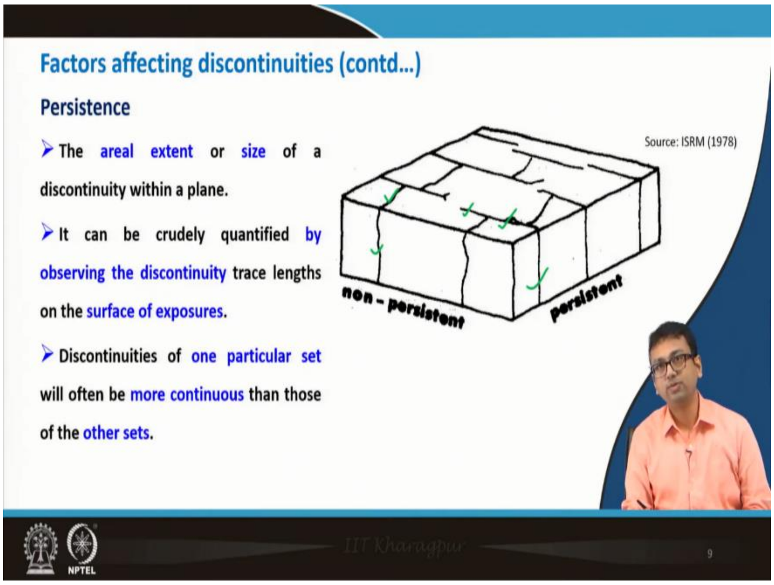

Now, another term is persistence. It is the areal extent or size of a discontinuity within a plane. It can be crudely quantified by observing the discontinuity trace length on the surface of exposure. The discontinuities of one particular set will often be more continuous than those of the others.

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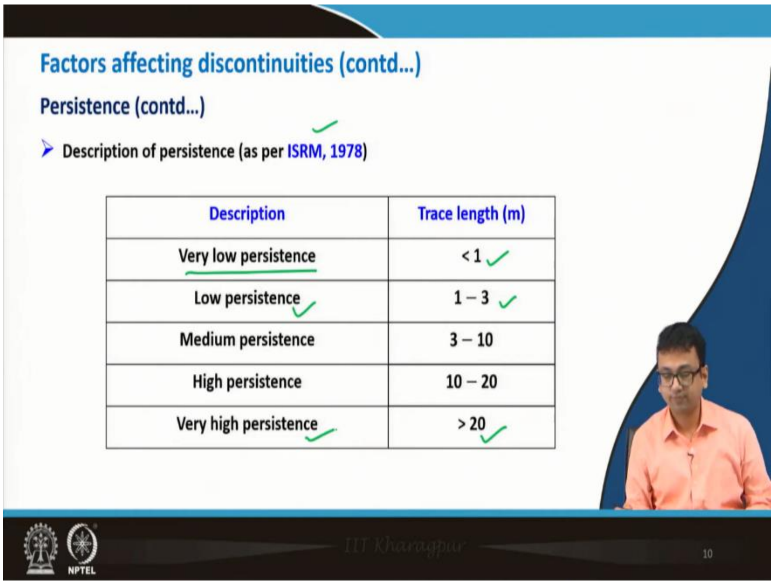

ISRM has given some description of persistence also. It says, if the trace length is less than 1 metre, very low persistence. Likewise, 1 to 3 low persistence and greater than 20 metre then very high persistence.

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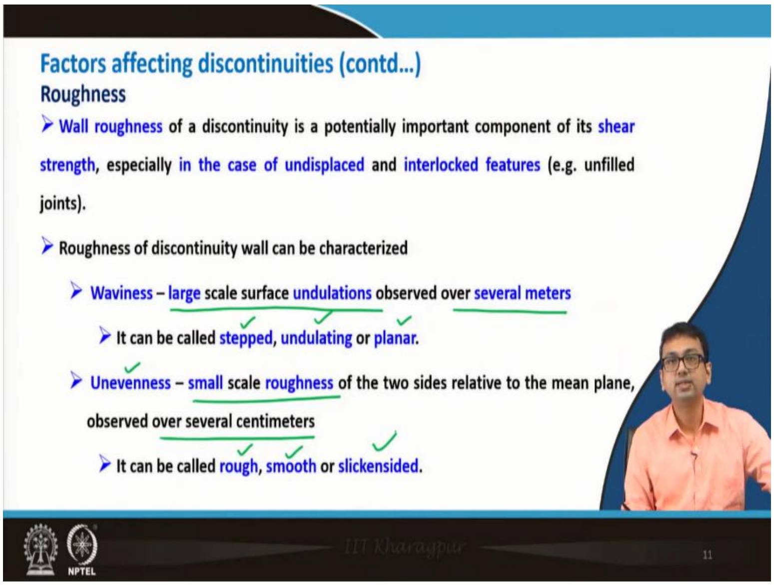

Another parameter is roughness. So, wall roughness of a discontinuity is a potentially important component of its shear strength especially, in the case of undisplaced and interlocked features, for example, unfilled joints. Now roughness of the discontinuity wall can be characterized by waviness and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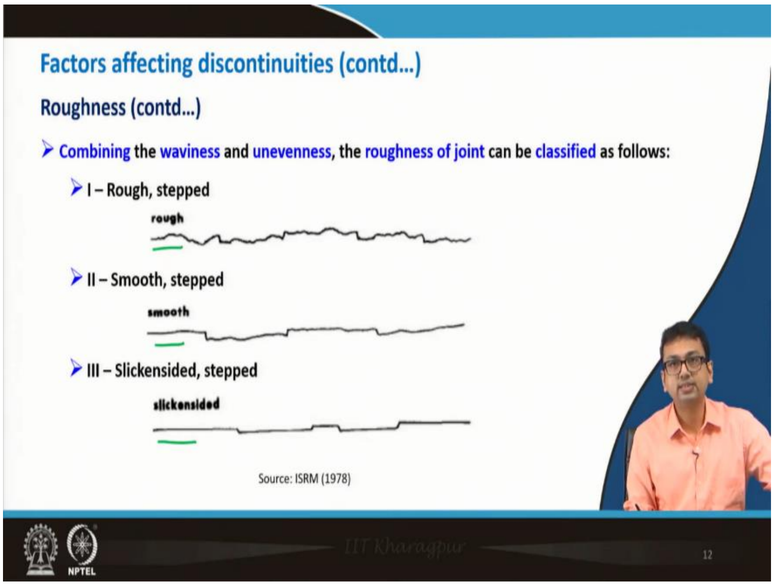

So, refer to slides, combining the waviness and unevenness, the roughness of joints can be classified as follows, this is as per ISRM 1978 only. First is rough and stepped, second is smooth and stepped, third is slickensided and stepped.

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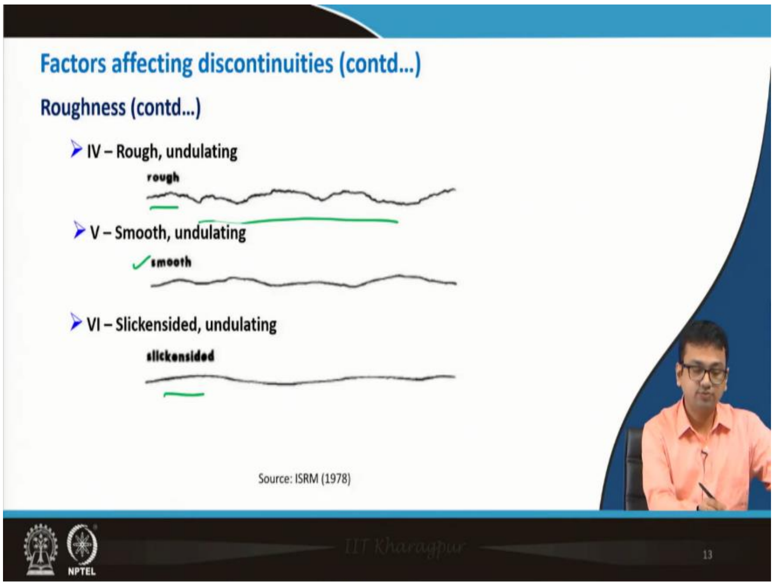

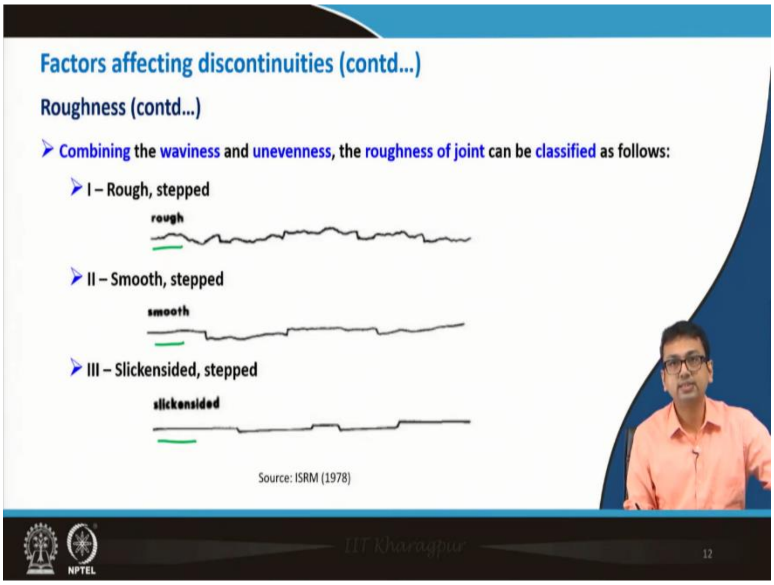

Fourth, fifth and sixth are rough undulating, smooth undulating and slickensided undulating patterns.

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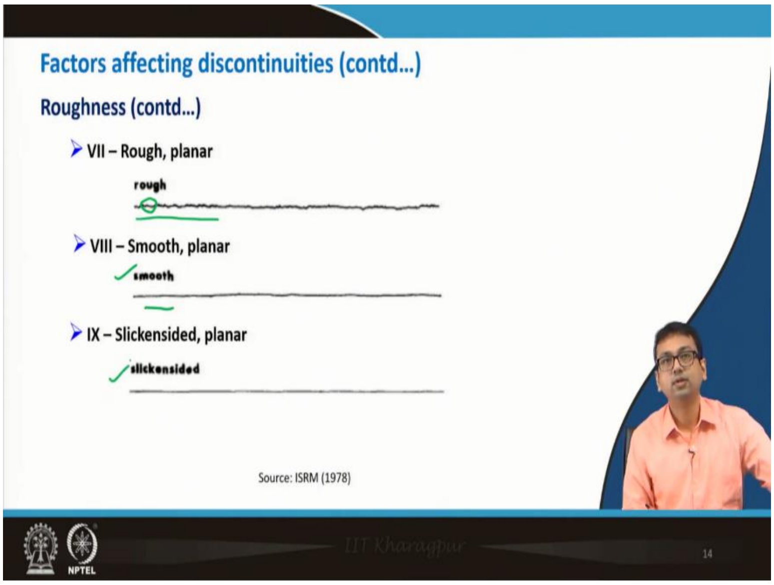

Seventh is rough planar, eighth is smooth planar and last one is slickensided planar.

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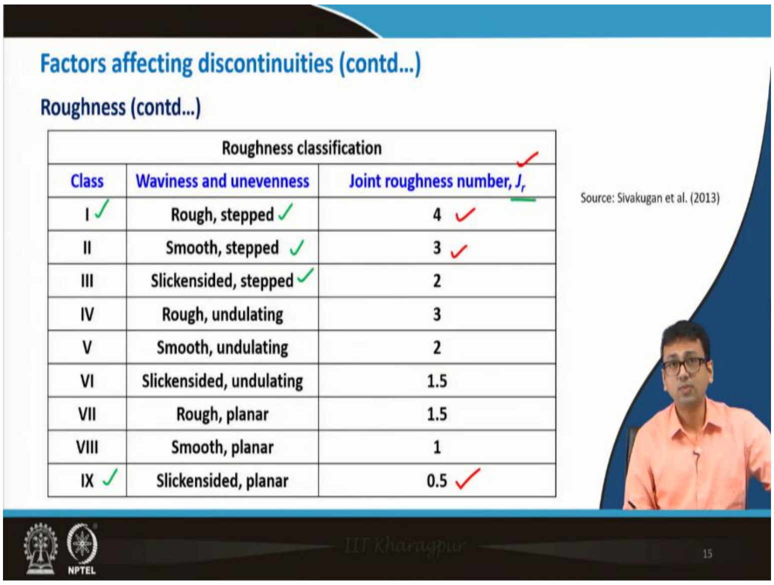

Therefore, based on waviness and unevenness, discontinuities can be classified.

Now, Jr, 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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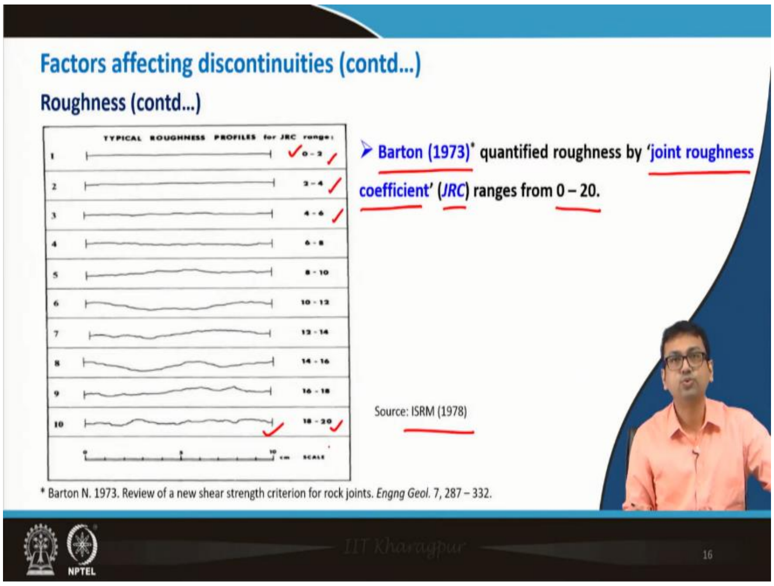

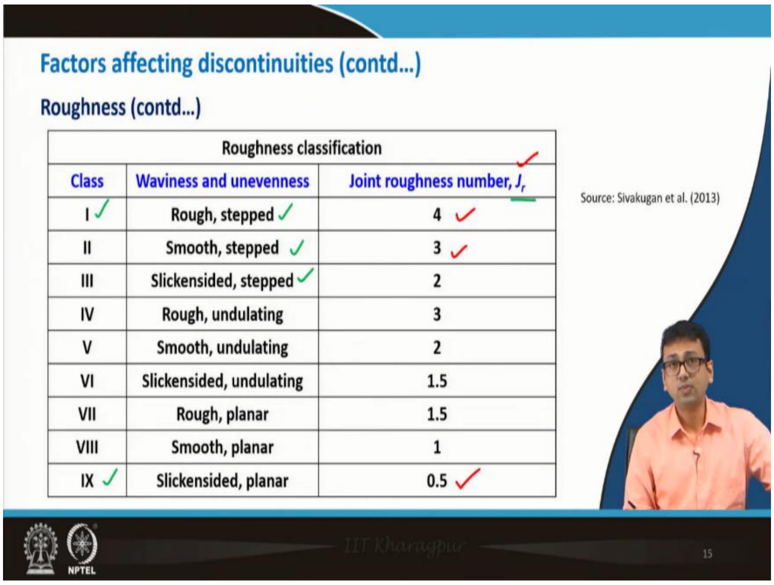

Barton in 1973 quantified roughness by joint roughness coefficient JRC. In future you may see this term we are using, joint roughness coefficient JRC. Its range is from 0 to 20 and it is graded as per the roughness. You can find this in ISRM 1978 only.

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

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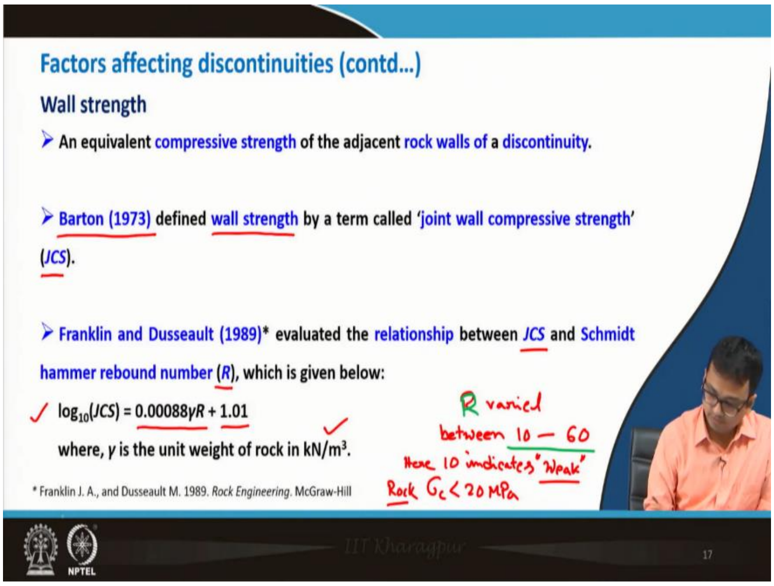

Wall strength is another important parameter that affects the discontinuity. It is an equivalent compressive strength of the adjacent rock walls of a discontinuity. Barton 1973 defined wall strength by a term called joint wall compressive strength JCS.

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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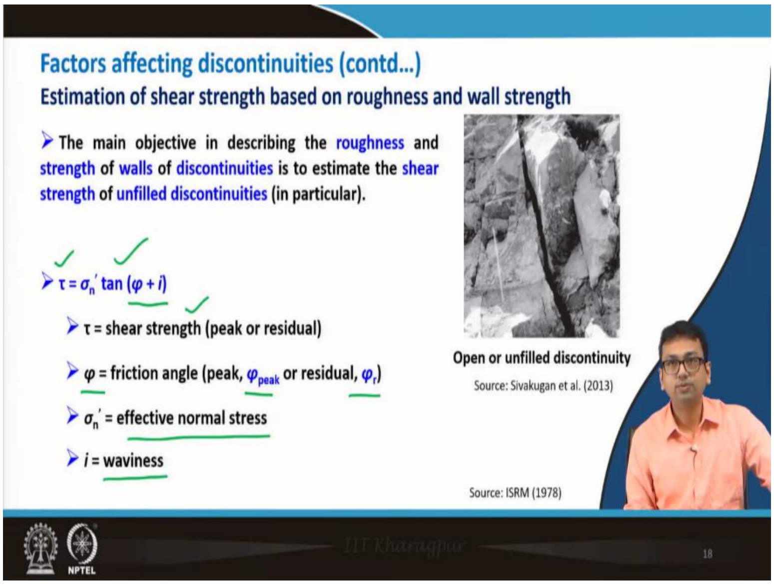

So, now estimation of shear strength based on roughness and wall strength. The main objective in describing the roughness and strength of walls of discontinuities is to estimate the shear strength of unfilled discontinuities particularly.

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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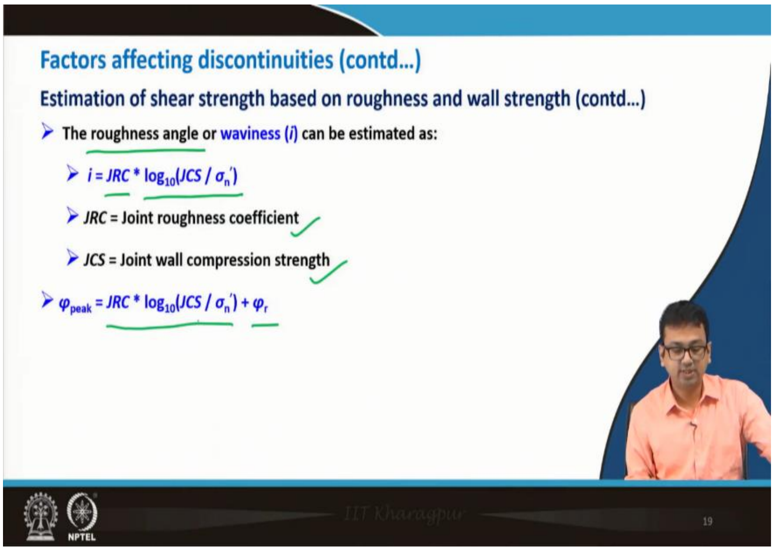

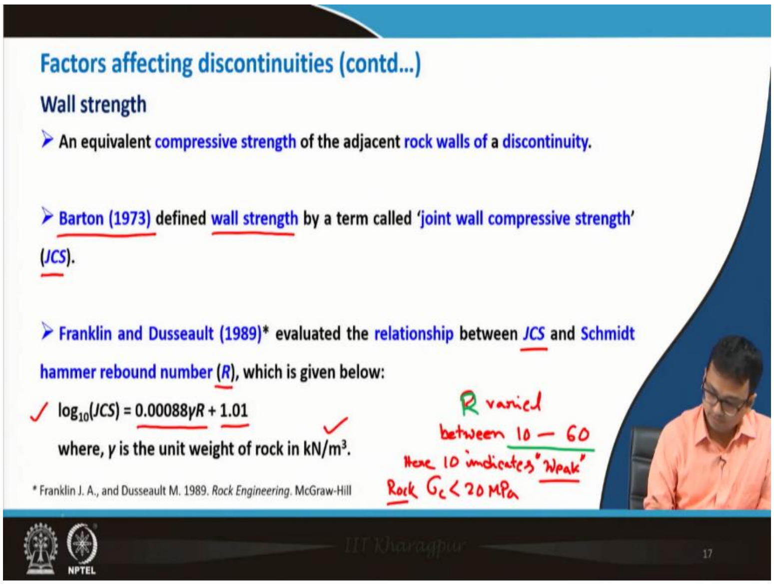

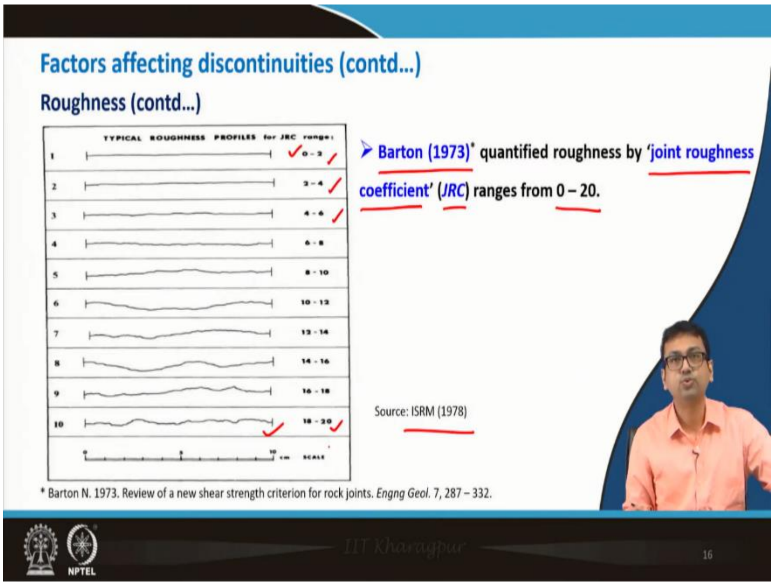

Now, the roughness angle or waviness, so that is a new term can be estimated as $i = JRC * \log_{10}(JCS/\sigma_n')$ where JRC and JCS joint wall compressive strength and joint roughness coefficient respectively.

To find phi peak if we know phi r, the equation is as follows $\phi_{peak} = JRC * \log_{10}(JCS/\sigma_n') + \phi_r$

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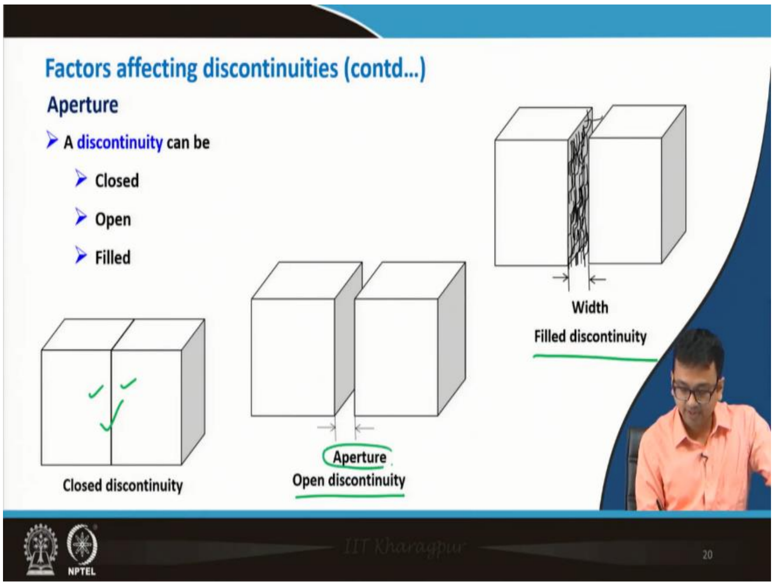

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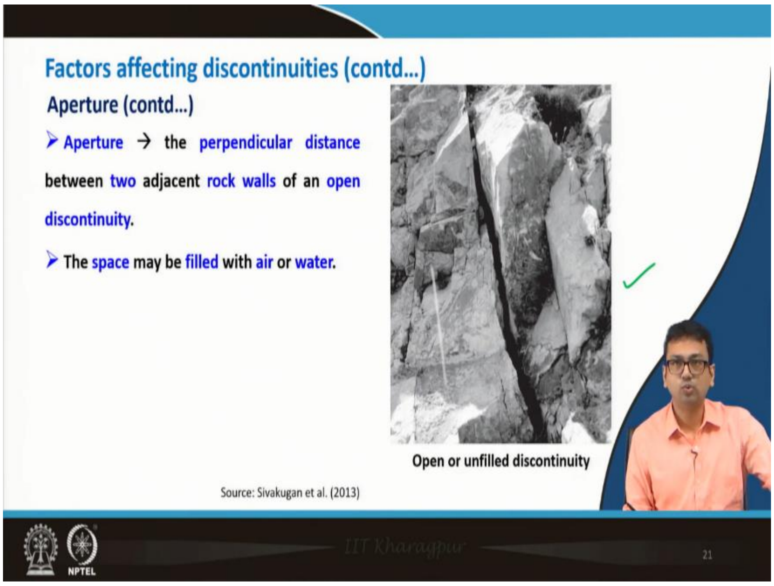

Aperture is the perpendicular distance between two adjacent rock walls of an open discontinuity. The space (if present) may be filled with air or water.

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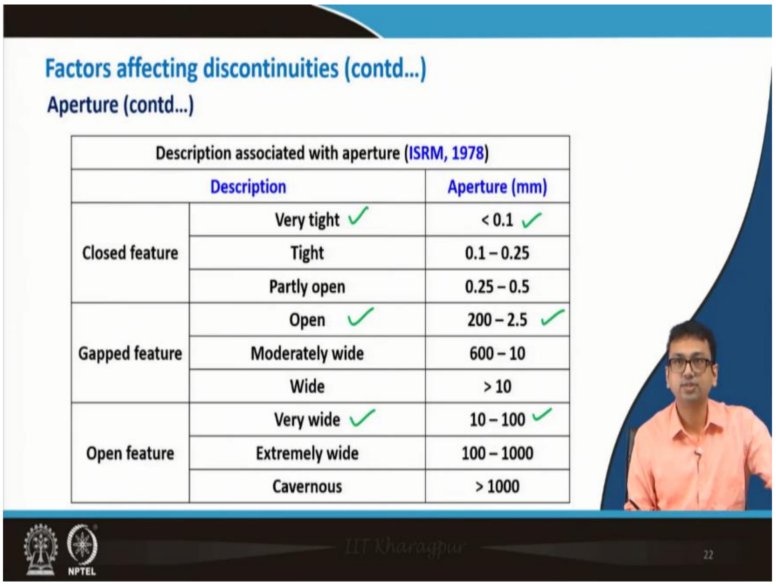

Now, based on this aperture, ISRM has given some descriptions like if it is very tight, then the aperture must be less than 0.1 millimetres likewise if it is open then 200 to 2.5 millimetres aperture. Likewise, if it is very wide then 10 to 100 millimetres aperture. So, this is again a useful table and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

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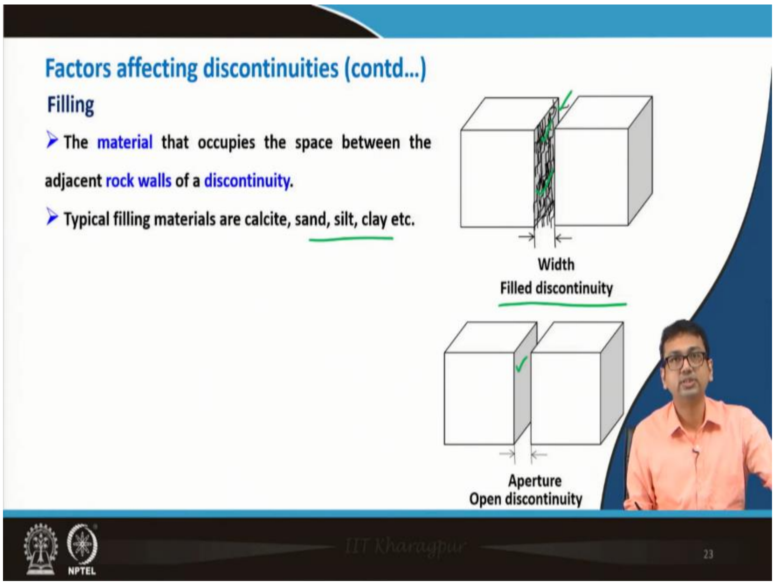

Now we will discuss filling. The material that occupies the space between the adjacent rock walls of a discontinuity is nothing but the filling. Now, typical filling materials are sand, silt, clay, calcite, etc.

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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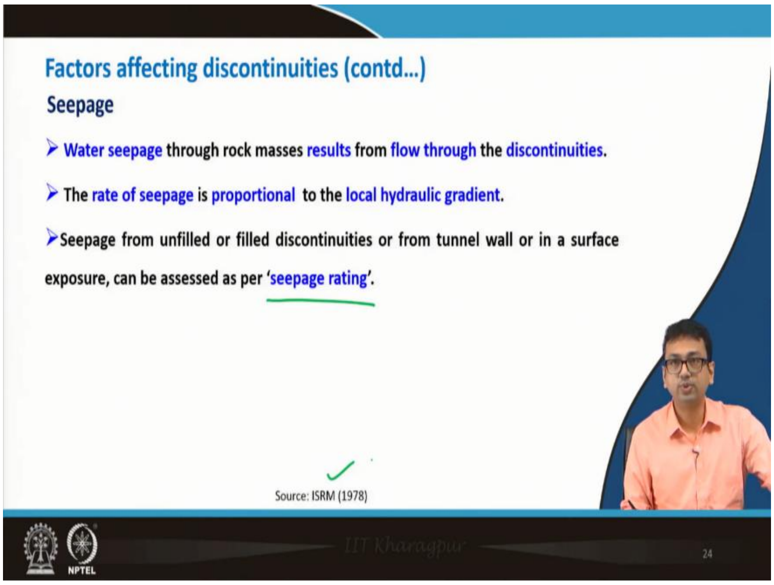

Now, another term is seepage, it also affects the performance of the discontinuity. The water seepage through rock masses results in flow through the discontinuities. The rate of seepage is proportional to the local hydraulic gradient.

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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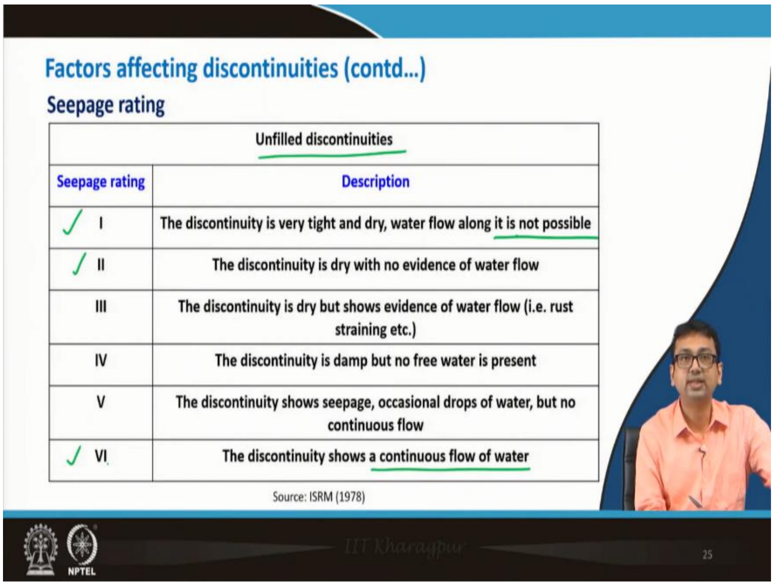

Let us see what is there. The first seepage rating is for unfilled discontinuities. Seepage ratings are given by 1, 2 likewise up to 6,1 indicates discontinuity is very tight and dry, water flow along it is not possible. Likewise, if we see the sixth one, the discontinuity shows a continuous flow of water.

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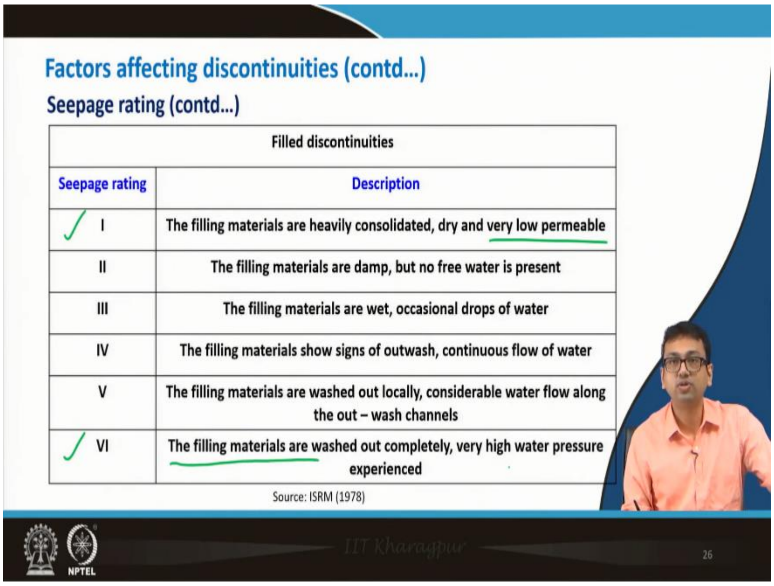

Similarly, for filled discontinuity there are similar ratings from 1 to 6, we can see 1 indicates the filling materials are heavily consolidated, dry and very low permeable. And if it is stated the seepage rating is 6 for filled discontinuity, we can say that the filling materials are washed out completely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

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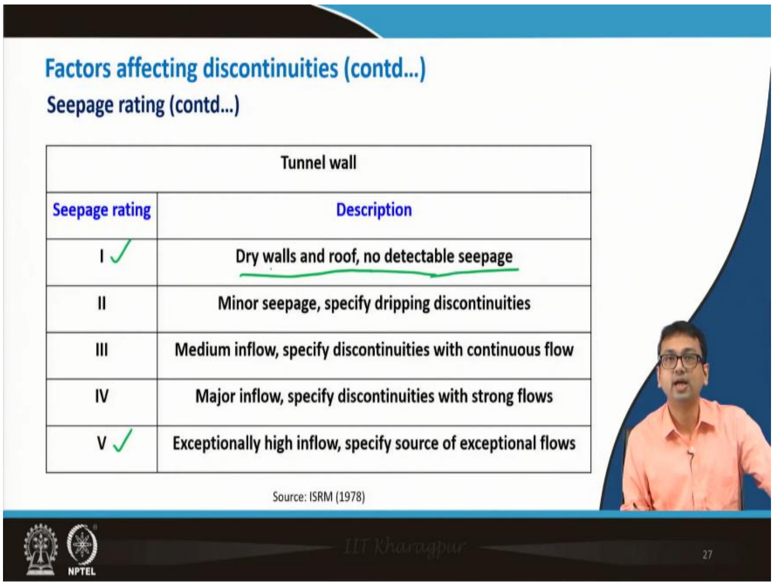

Likewise, the third one is related to the tunnel. For tunnel walls also ISRM in 1978 gave some guidelines like seepage rating from 1 to 5. 1 indicates dry wall and roof no detectable seepage. Second one is minor seepage, specify dripping discontinuities.

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

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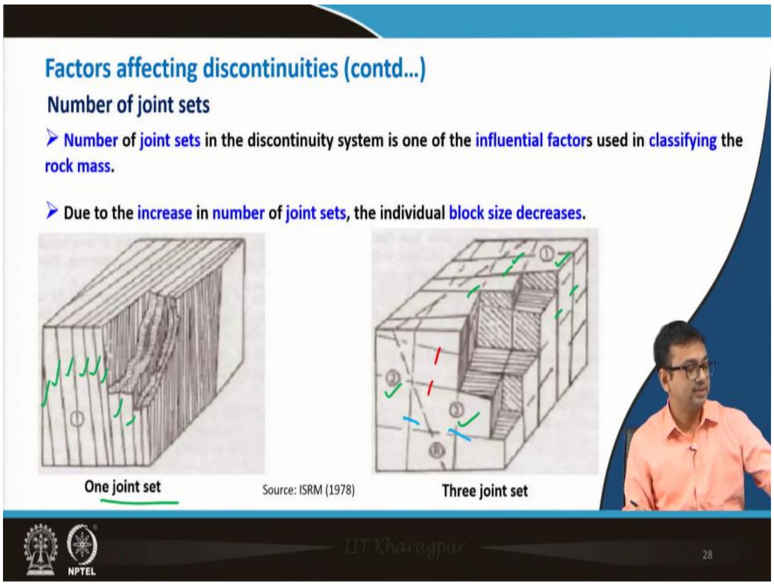

Now, next one is number of joint sets. So, regarding joint set we have already discussed while discussing the spacing. Number of joint sets in the discontinuity system is one of the influential factor used in classifying the rock mass. So, due to the increase in number of joint set the individual block 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.

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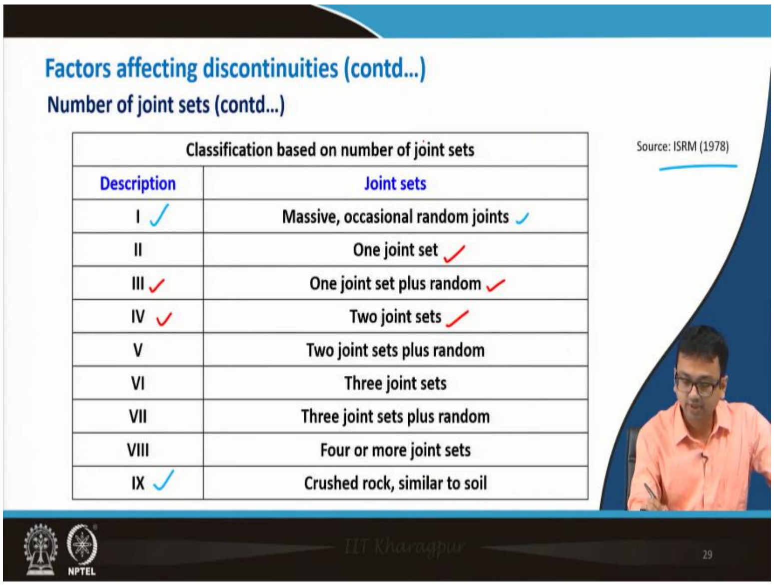
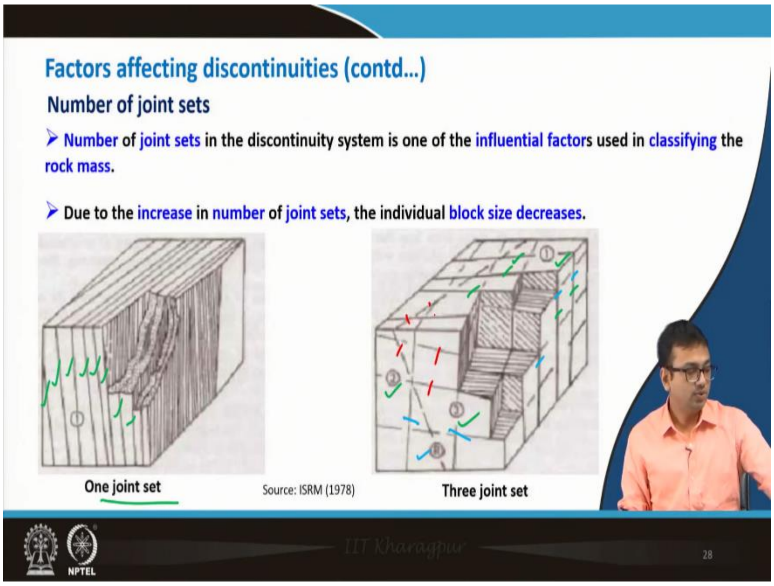


Classification based on number of joint sets	
Description	Joint sets
I	Massive, occasional random joints
II	One joint set
III	One joint set plus random
IV	Two joint sets
V	Two joint sets plus random
VI	Three joint sets
VII	Three joint sets plus random
VIII	Four or more joint sets
IX	Crushed rock, similar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



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.

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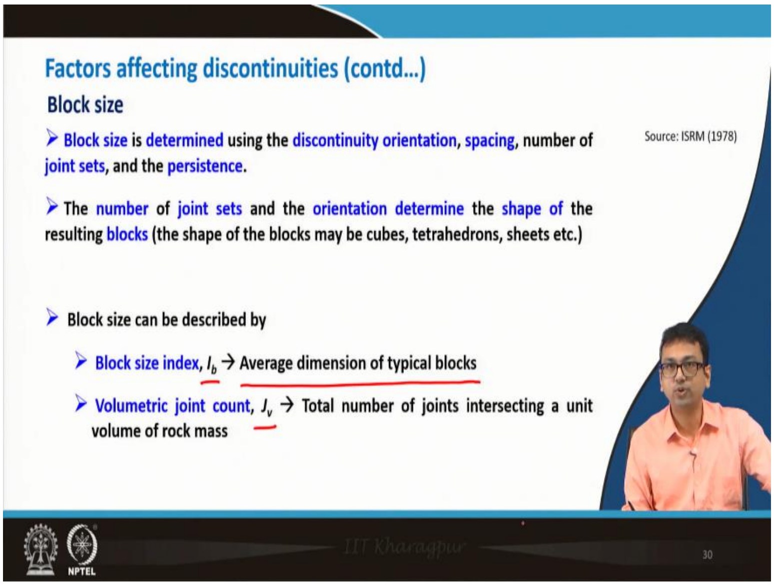

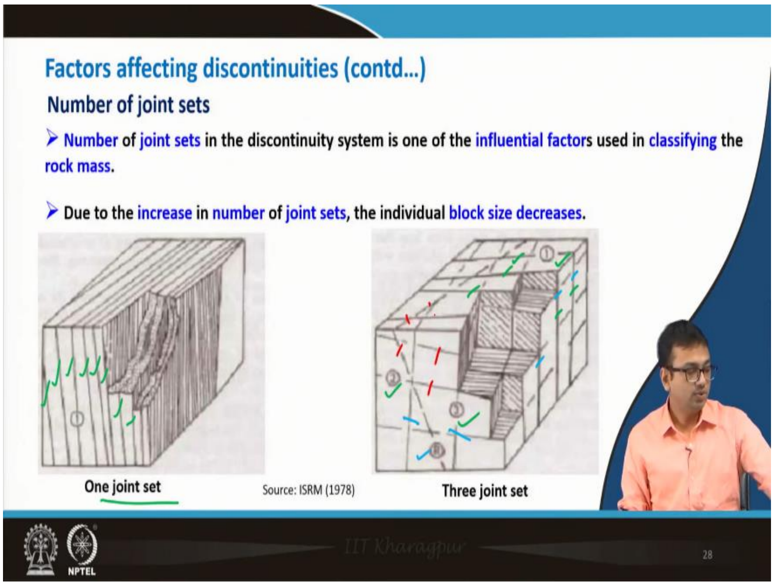

Next is block size. So, block size is very much related to the joint set as I have stated just couple of slides back that due to the increase in the number of joint sets the individual block size decreases obviously. Now block size is determined using discontinuity orientation, spacing, number of joint 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.

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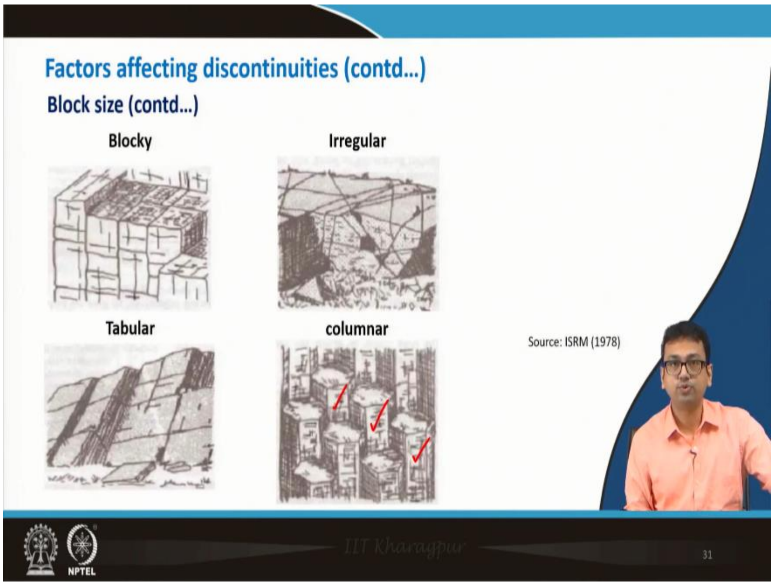

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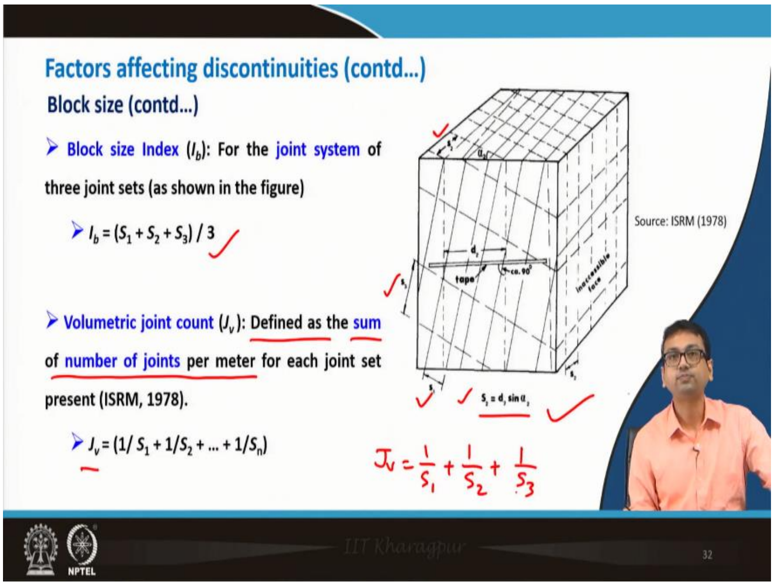

Now, refer to the diagram in the slide which we have already discussed while discussing spacing. We have calculated S_1, S_2 and S_3 using d_1, d_2 and d_3 and α_1, α_2 and α_3. So, I_b can be calculated as $I_b = (S_1 + S_2 + S_3)/3$.

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. Jv can be calculated as $J_V = (1/S_1 + 1/S_2 + ... + 1/S_n)$

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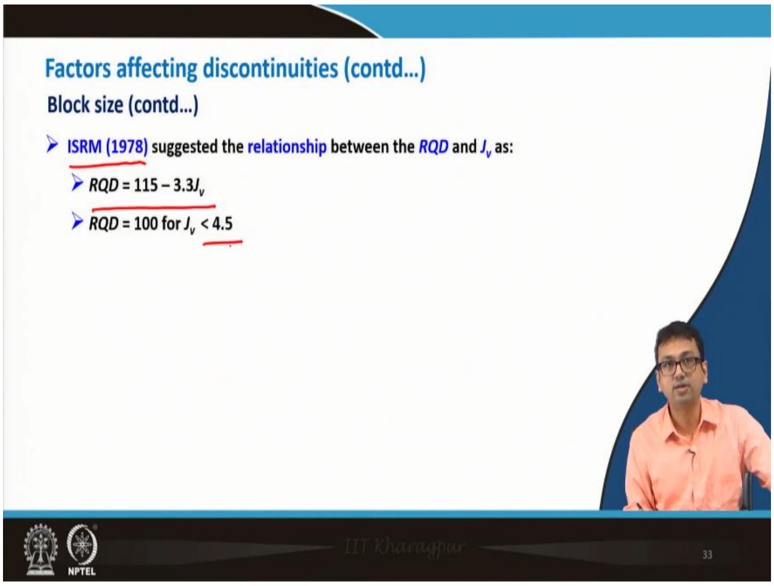

J_v is important because ISRM 1978 suggests the relationship between the RQD and J_v. RQD, is rock quality designation. So, RQD as per ISRM 1978 can be obtained using this J_v

$$RQD = 115 - 3.3J_V$$

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

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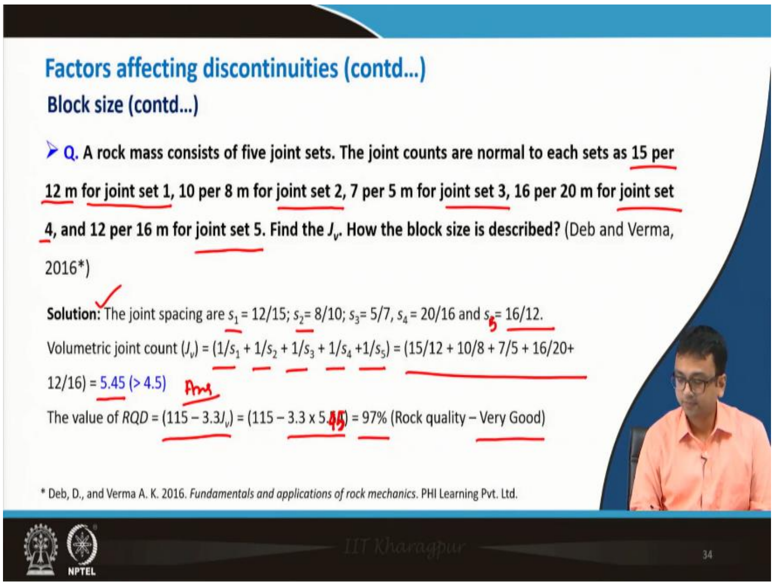

Now, let us take a small problem and with this we will conclude. So, you see a small problem that will clear out your doubt regarding Jv.

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

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.